

Monte Carlo Methods for neutrino-nucleus scattering

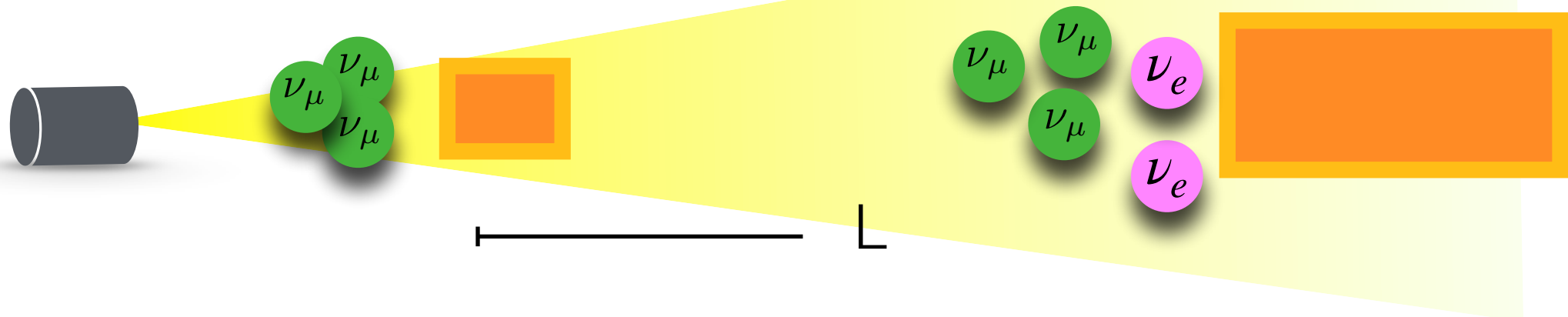
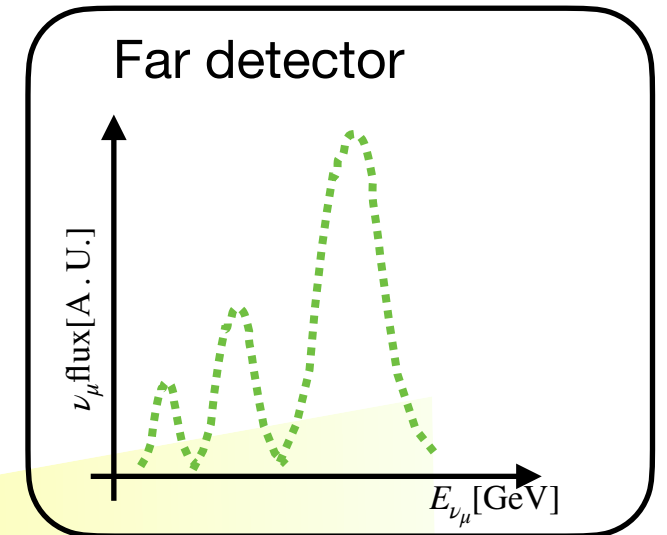
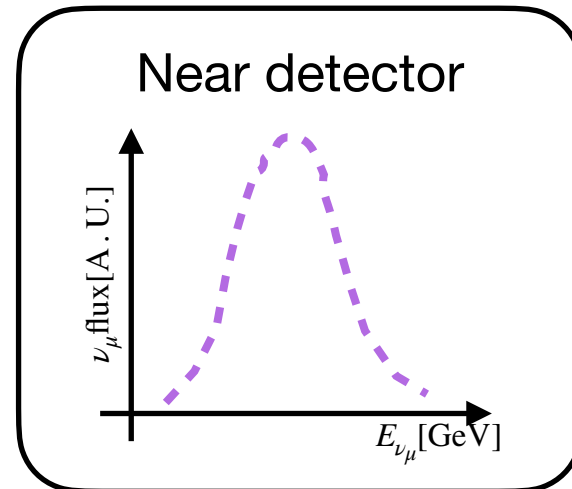
NSTAR2026 — September 7-11, 2026, Seville

Noemi Rocco

Why do we need more precision?



New generation of neutrino experiments will measure the unknown PMNS parameters with unprecedented accuracy



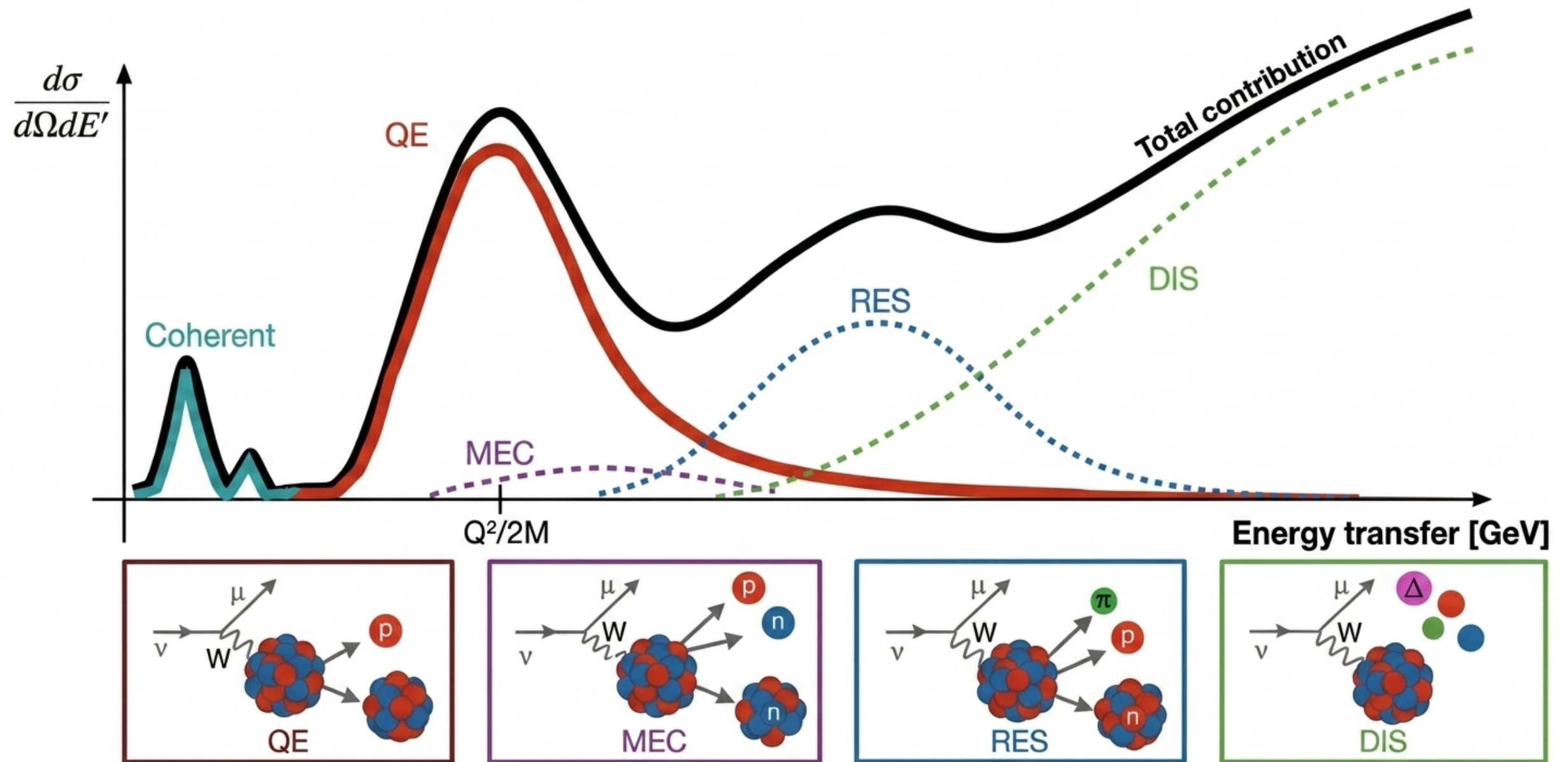
$$P(\nu_\mu \rightarrow \nu_e, E_\nu, L) = \frac{\Phi(E_\nu, L)}{\Phi_\mu(E_\nu, 0)} = \frac{\frac{N_e(E_\nu, L)}{\sigma_e(E_\nu)}}{\frac{N_\mu(E_\nu, L)}{\sigma_\mu(E_\nu)}}$$

Theory ↖

Experiment ↖

See **S.Dolan's** talk
[“CP Violation or
 Nuclear excitation”](#)

Lepton-nucleus cross section



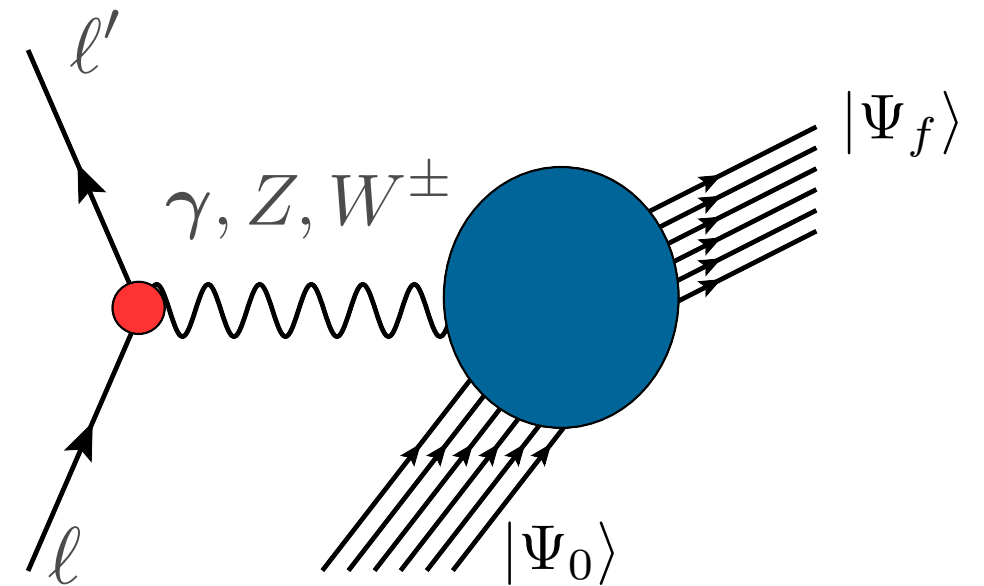
Theory of lepton-nucleus scattering

- The cross section of the process in which a lepton scatters off a nucleus is

$$d\sigma \propto L^{\alpha\beta} R_{\alpha\beta}$$

Leptonic Tensor: is the same as before, completely determined by lepton kinematics

Hadronic Tensor: nuclear response function



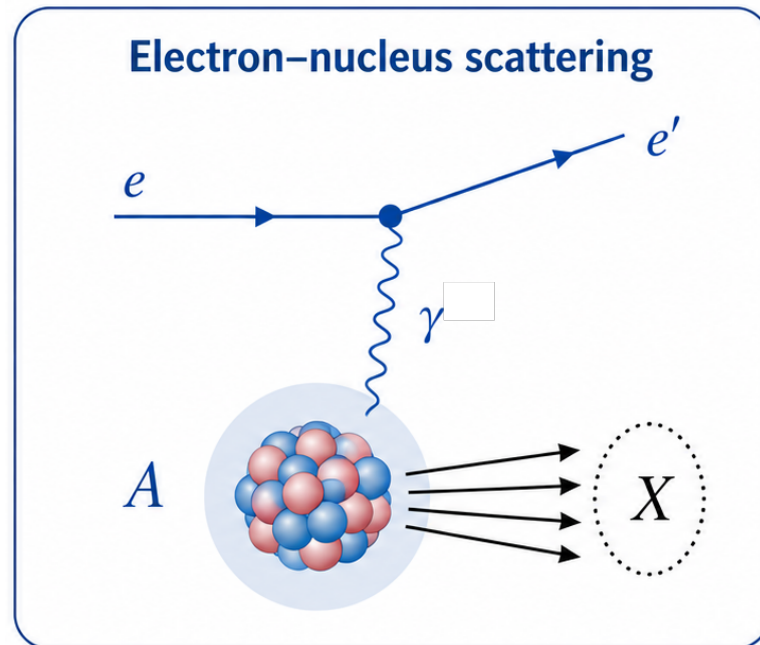
$$R_{\alpha\beta}(\omega, \mathbf{q}) = \sum_f \langle 0 | J_{\alpha}^{\dagger}(\mathbf{q}) | f \rangle \langle f | J_{\beta}(\mathbf{q}) | 0 \rangle \delta(\omega - E_f + E_0)$$

The initial and final wave functions describe many-body states:

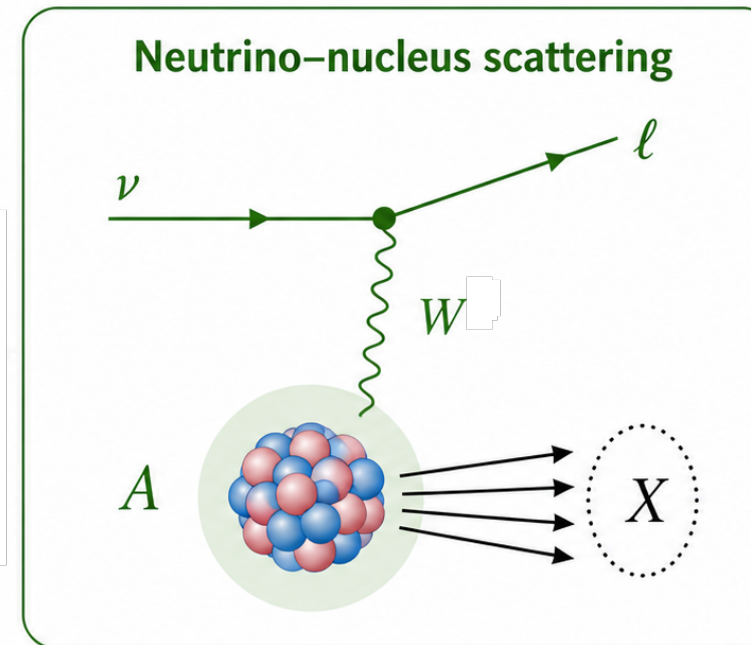
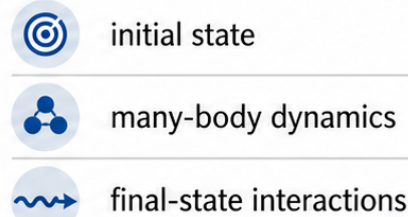
$$|0\rangle = |\Psi_0^A\rangle, |f\rangle = |\Psi_f^A\rangle, |\psi_p^N, \Psi_f^{A-1}\rangle, |\psi_k^{\pi}, \psi_p^N, \Psi_f^{A-1}\rangle \dots$$

For inclusive reactions, the hadronic final state is not detected. We need to sum over all the possible ones

Using electrons to better understand neutrinos



$$e + A \rightarrow e' + X$$

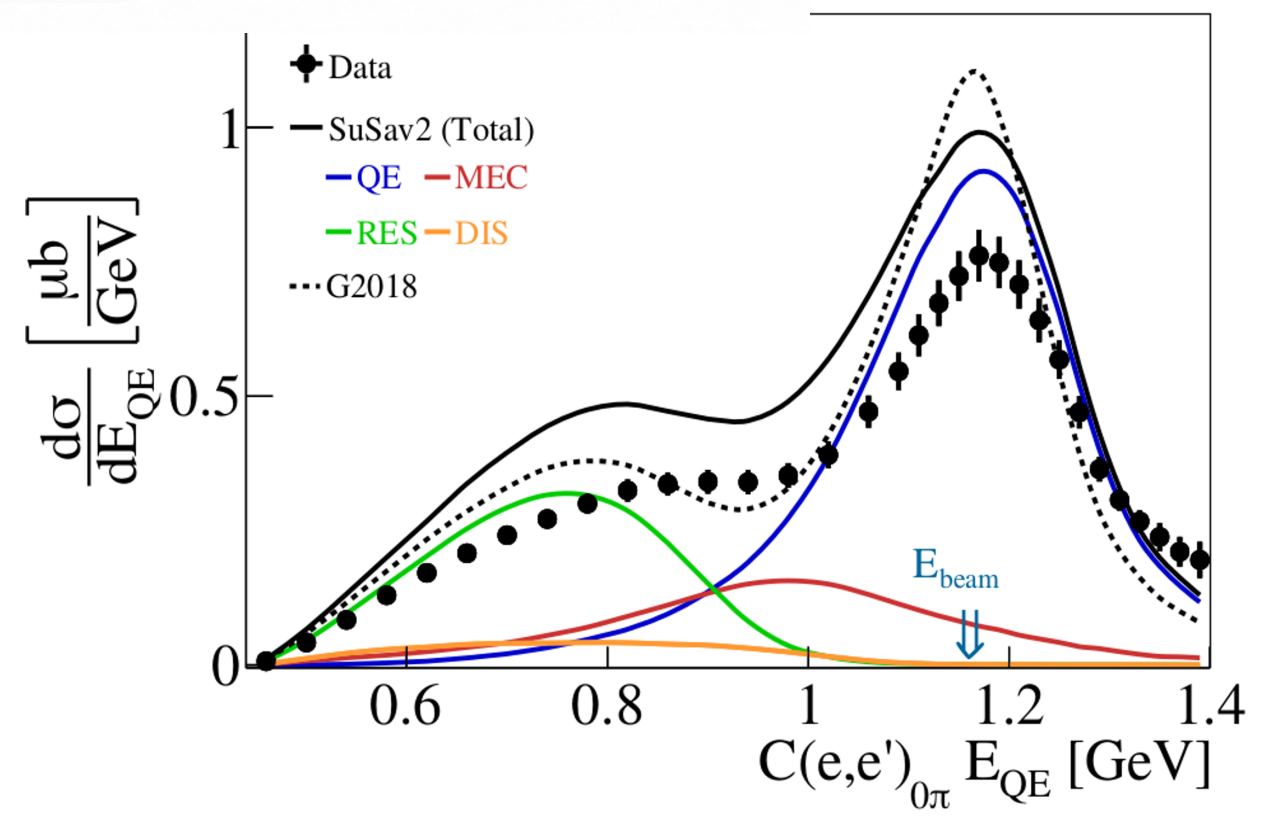


$$\nu + A \rightarrow \ell + X$$

See **J.Tena Vidal's** talk
[“New electron scattering pion-production constraints for neutrino event generators”](#)

CLAS and e4v collaboration,
Nature 599 (2021) 7886, 565-570

Need for substantial improvement in the **accuracy** of the neutrino interactions' models and simulations



Ab initio theory achievements

Effective Hamiltonians and consistent currents

	NN	3N
LO $(Q/\Lambda_\chi)^0$		
NLO $(Q/\Lambda_\chi)^2$		
NNLO $(Q/\Lambda_\chi)^3$		

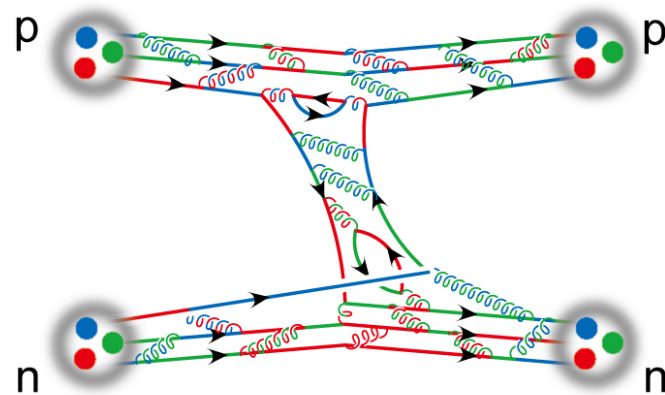
Accurate nuclear many-body methods



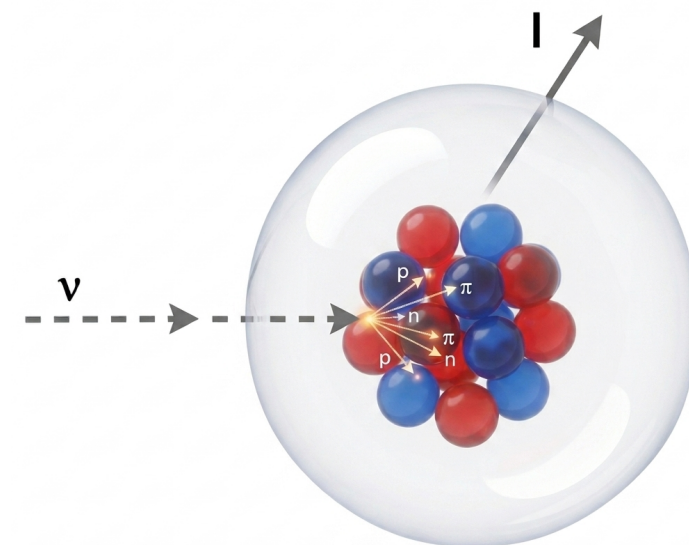
$$H|\Psi_n\rangle = E_n|\Psi_n\rangle$$

$$J_{mn} = \langle\Psi_m|J|\Psi_n\rangle$$

Quantum Chromodynamics



Neutrino-nucleus interactions



Green's Function Monte Carlo approach

QMC techniques **projects out the exact lowest-energy state**: $e^{-(H-E_0)\tau} |\Psi_T\rangle \rightarrow |\Psi_0\rangle$

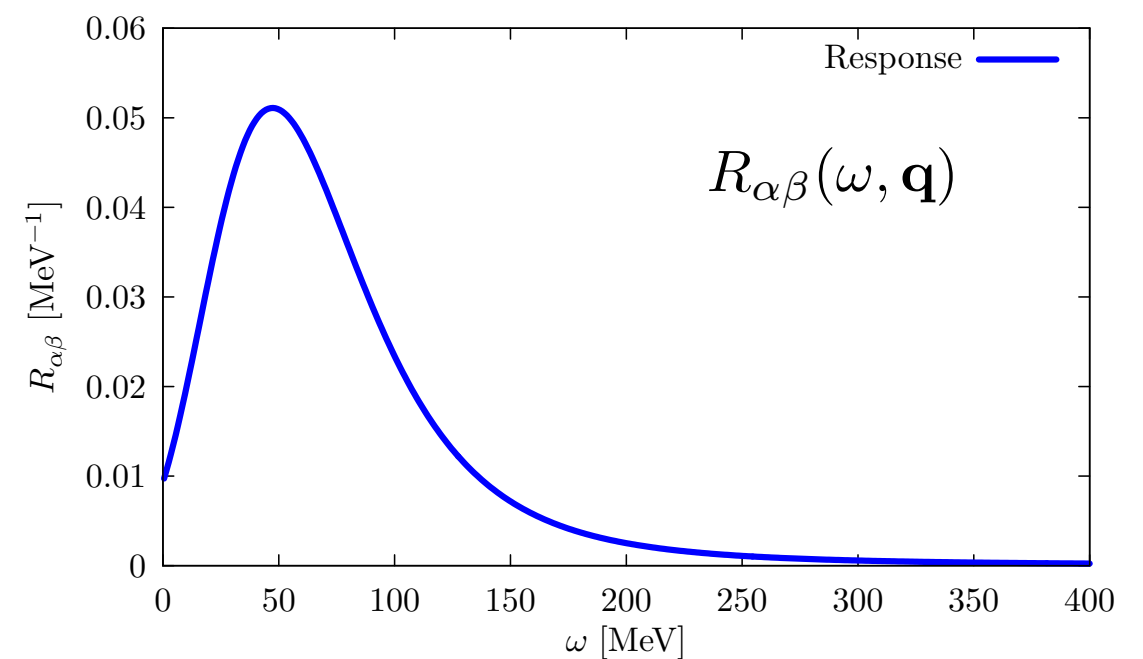
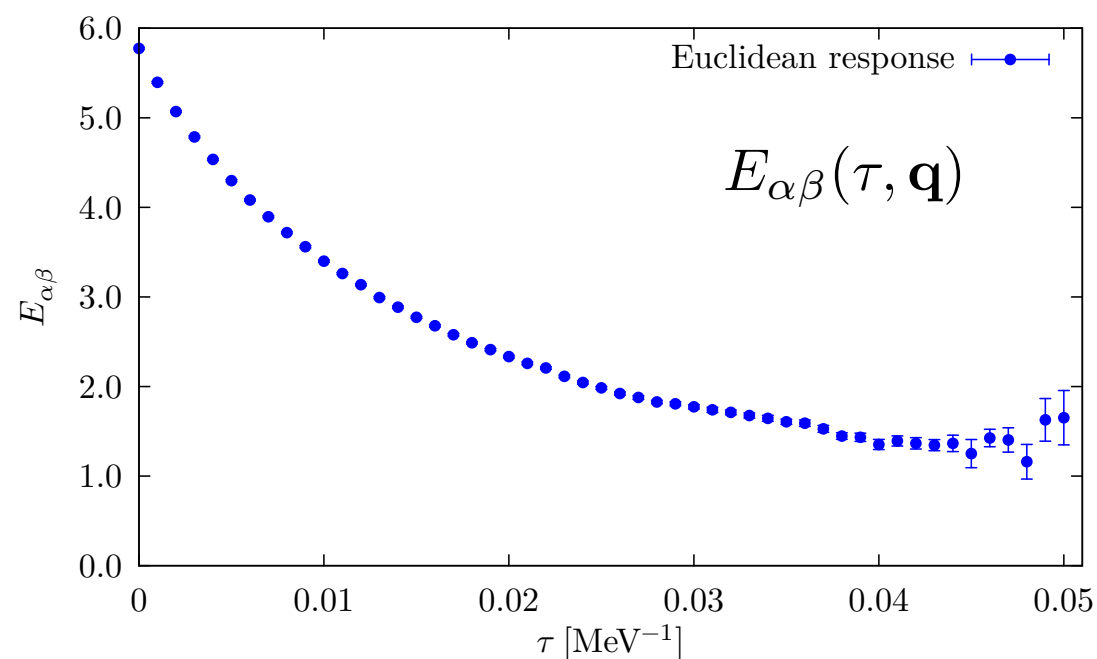
Nuclear response function involves evaluating a number of transition amplitudes.

Valuable information can be obtained from the **integral transform of the response function**

$$E_{\alpha\beta}(\sigma, \mathbf{q}) = \int d\omega K(\sigma, \omega) R_{\alpha\beta}(\omega, \mathbf{q}) = \langle \psi_0 | J_{\alpha}^{\dagger}(\mathbf{q}) K(\sigma, H - E_0) J_{\beta}(\mathbf{q}) | \psi_0 \rangle$$

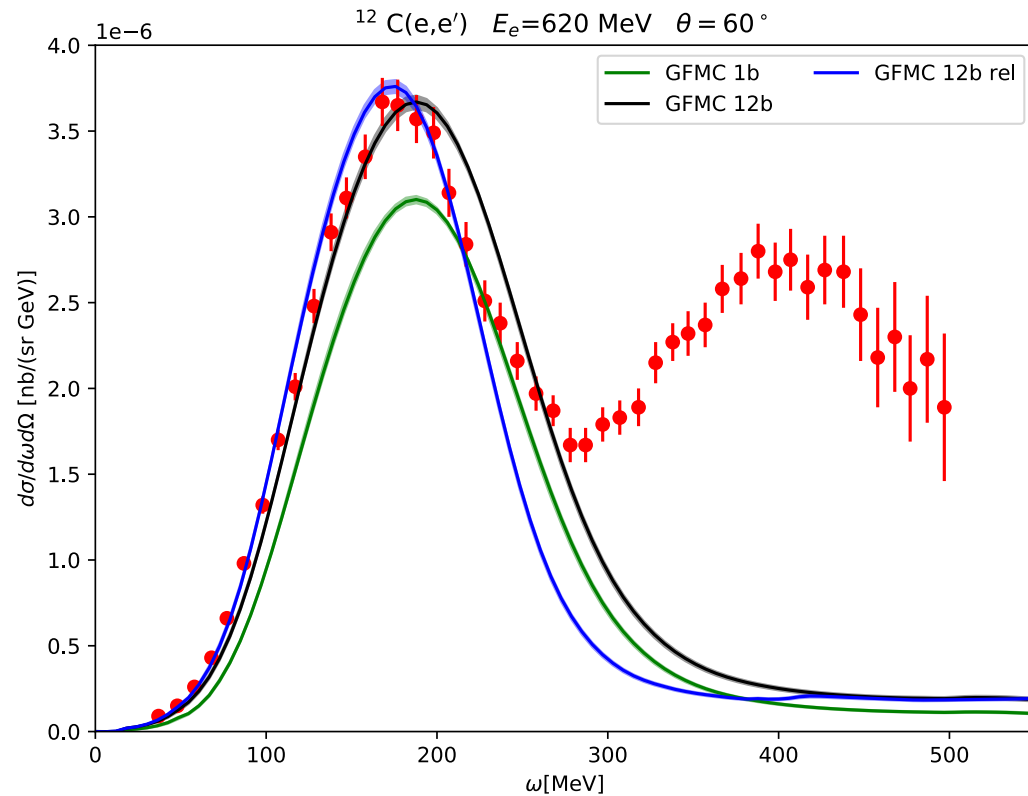
Inverting the Laplace transform is a complicated problem

[A. Lovato et al, PRL117 \(2016\), 082501, PRC97 \(2018\), 022502](#)



Same problem applies to different realm physics for example lattice QCD

Green's Function Monte Carlo approach



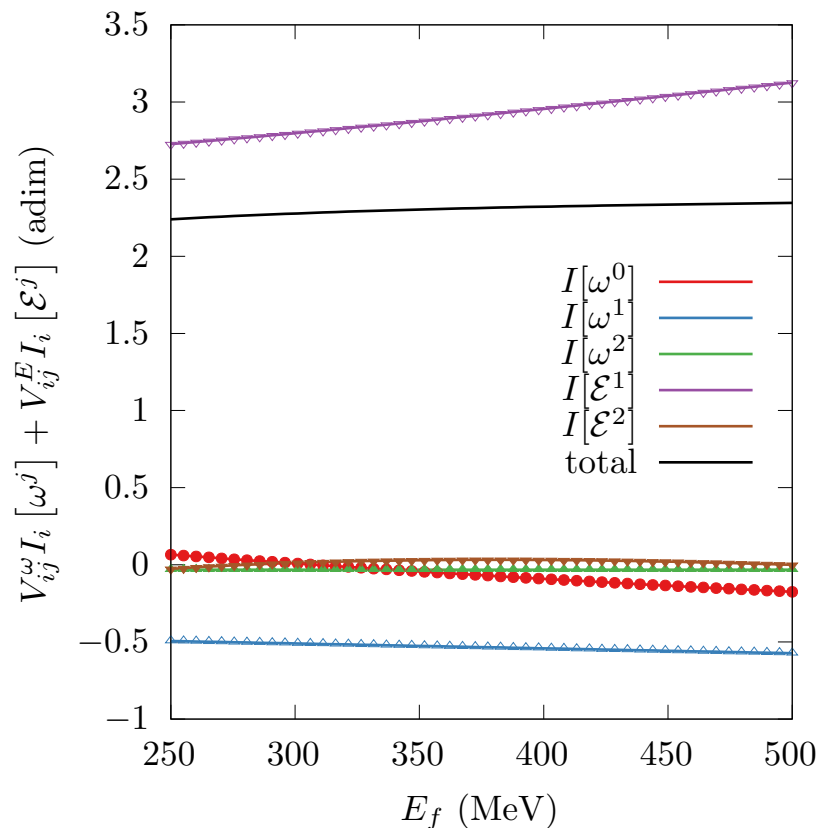
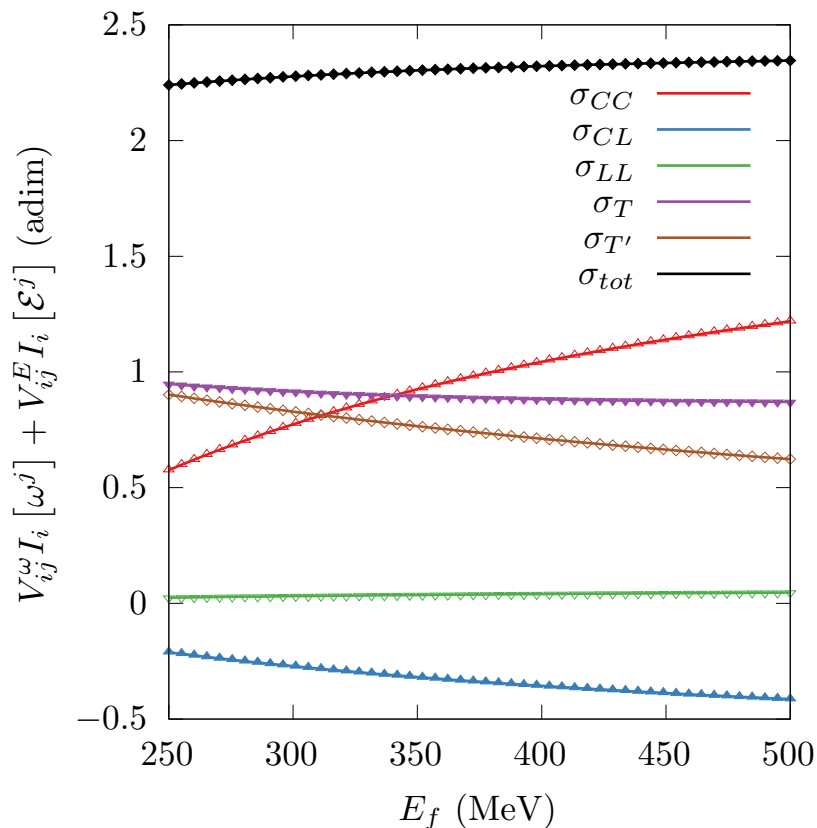
Inclusive results which are virtually correct in the QE

Different Hamiltonians can be used in the time-evolution operator

Relies on non-relativistic treatment of the kinematics

Can not handle explicit pion degrees of freedom

[A. Nikolakopoulos NR, 2603.13619](#)



Alternative method to avoid inversion

Energy-integrated ν cross sections at fixed $\mathbf{q}$ can be expressed in terms of energy-weighted integrals of $R(\omega, \mathbf{q})$

These quantities can be directly extracted from $E(\tau, \mathbf{q})$

Axial form factor

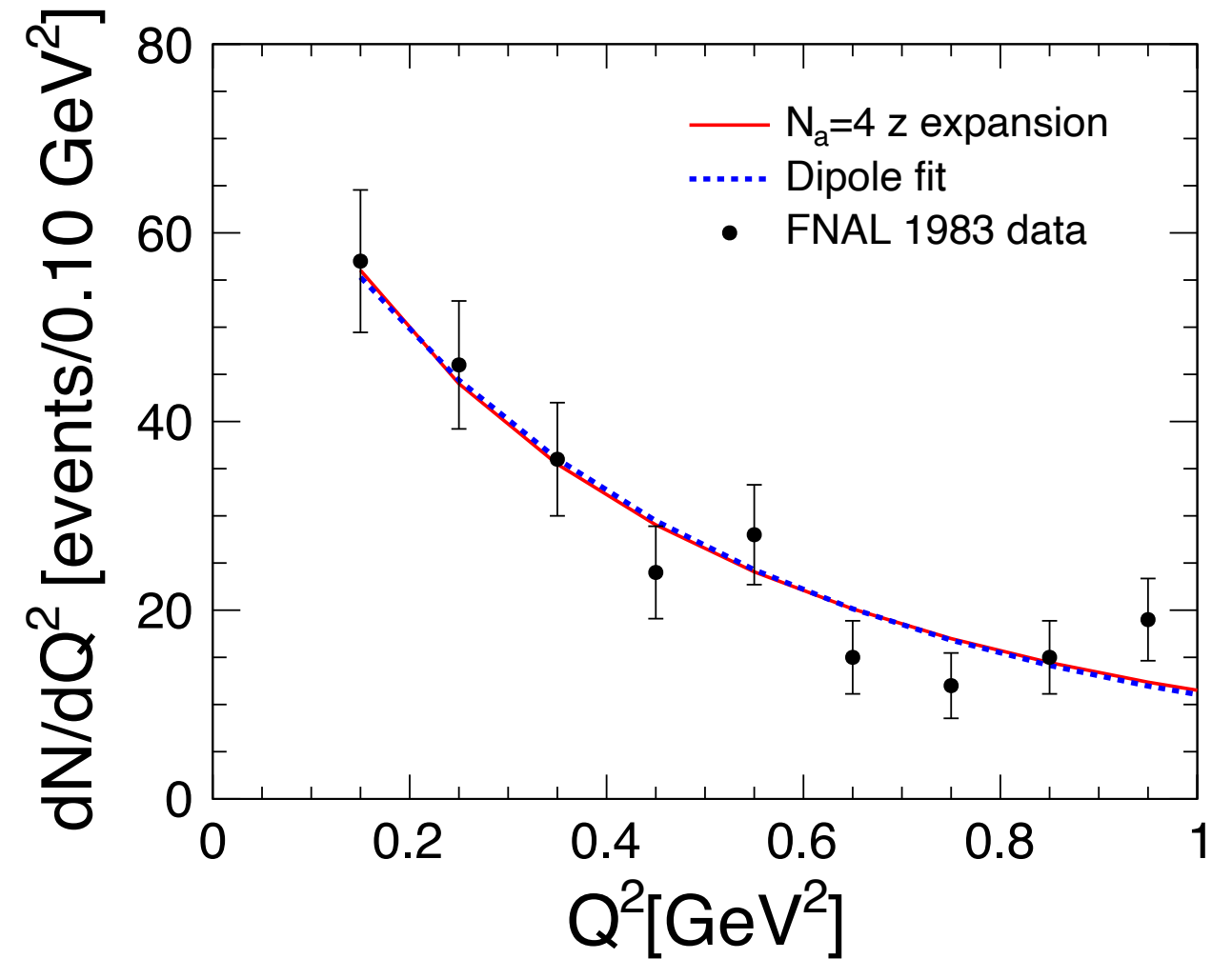
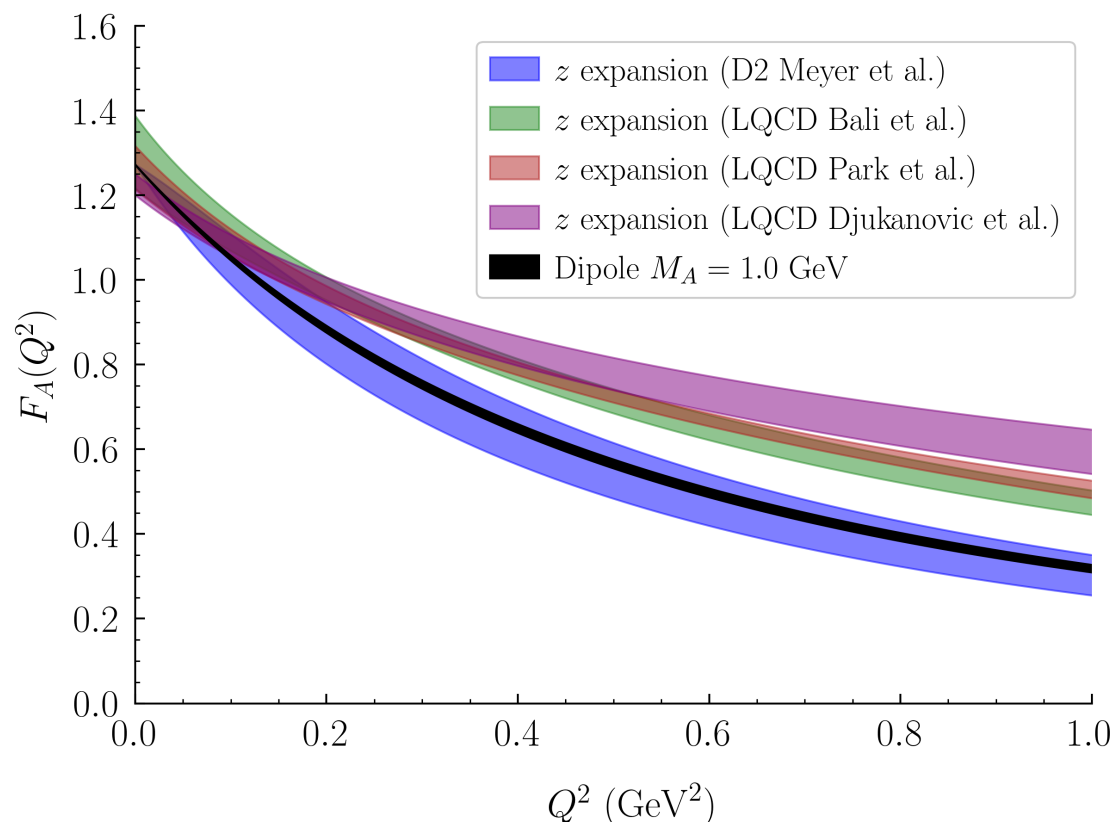
- Model independent **z-expansion**

$$F_A(q^2) = \sum_{k=0}^{k_{\max}} a_k z(q^2)^k,$$

free parameters a_k (indicated by a purple arrow pointing to a_k)
 known functions $z(q^2)^k$ (indicated by a purple arrow pointing to $z(q^2)^k$)

Bhattacharya, Hill, and Paz PRD 84 (2011) 073006

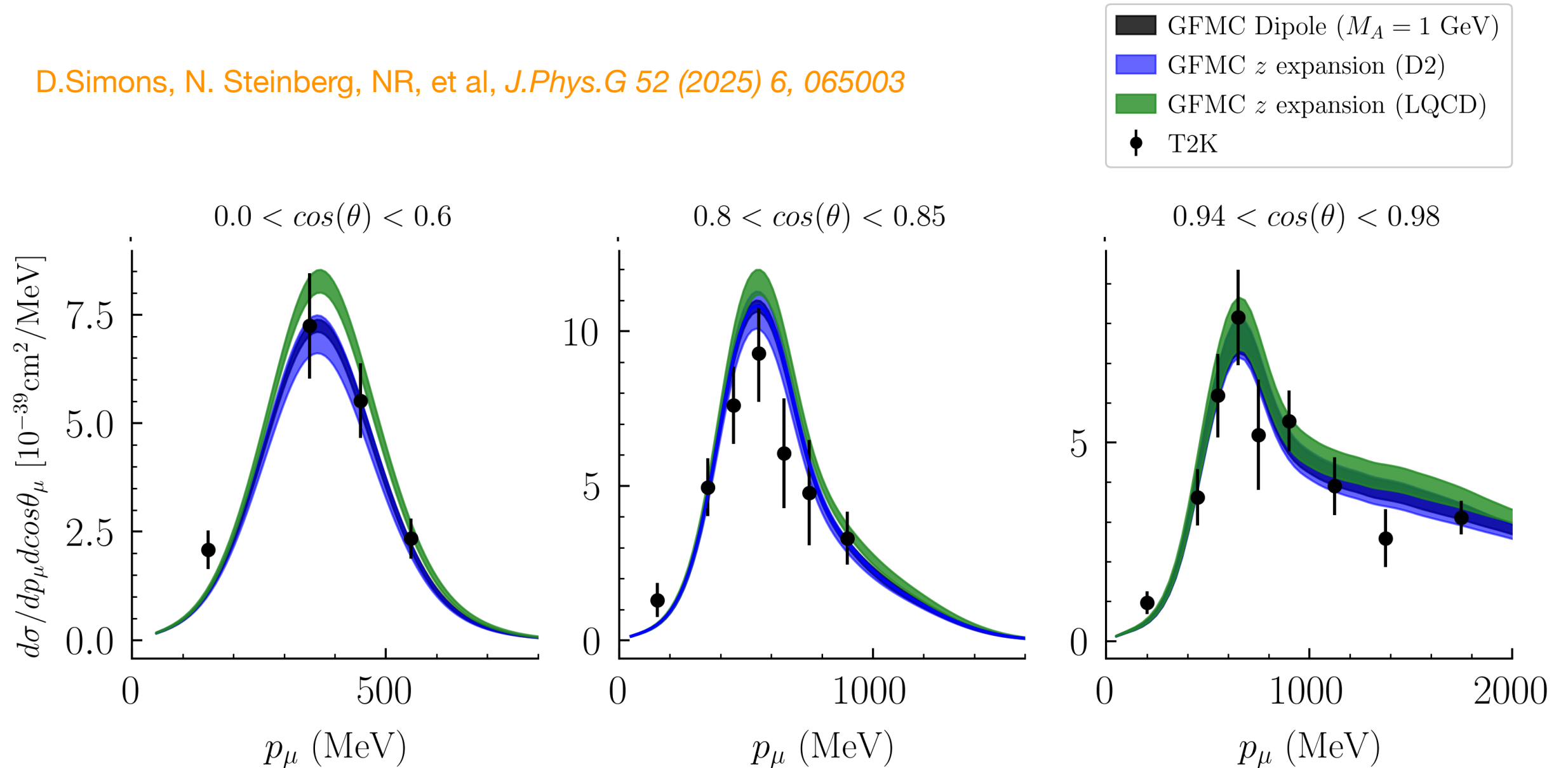
A.S.Meyer et al, Phys.Rev.D 93 (2016) 11, 113015



- D2 Meyer et al: fits to neutrino-deuteron scattering data
- LQCD result: general agreement between the different calculations
- LQCD results are 2-3 σ larger than D2 Meyer ones for $Q^2 > 0.3 \text{ GeV}^2$

Model dependence in T2K data

D.Simons, N. Steinberg, NR, et al, *J.Phys.G* 52 (2025) 6, 065003



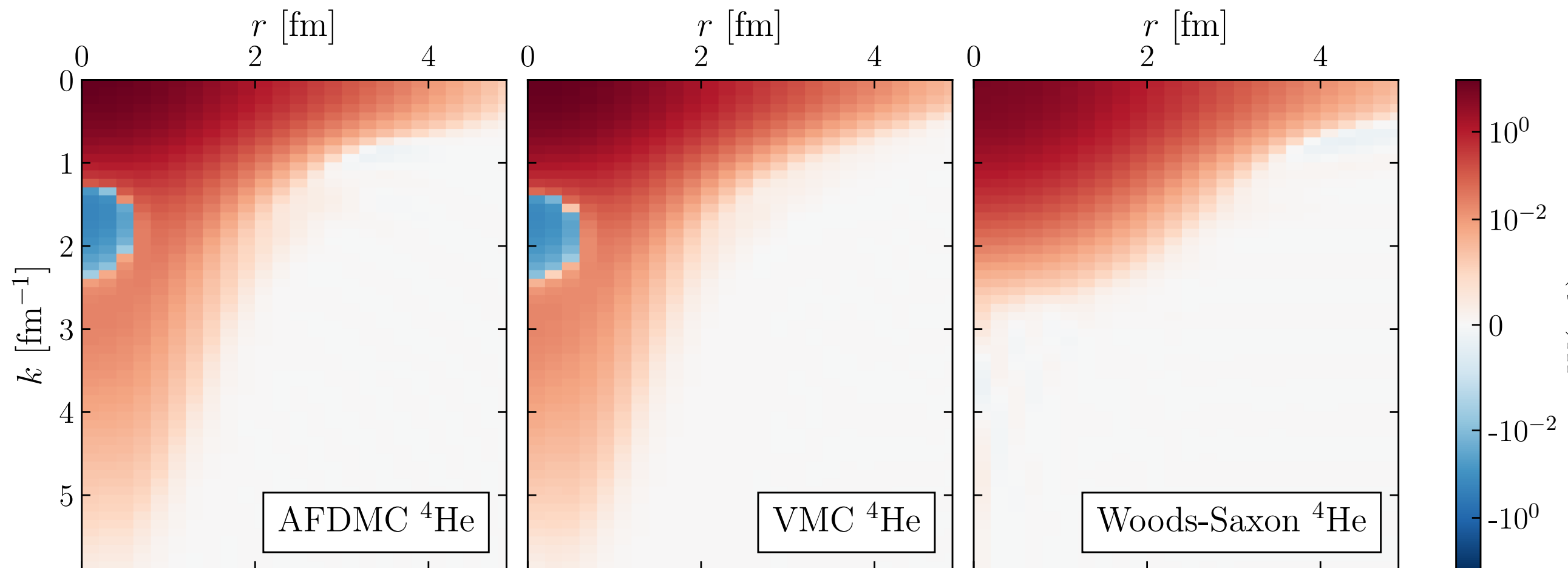
T2K	$0.0 < \cos \theta_\mu < 0.6$	$0.80 < \cos \theta_\mu < 0.85$	$0.94 < \cos \theta_\mu < 0.98$
GFMC difference in $d\sigma_{\text{peak}}$ (%)	15.8	8.0	4.6

Tomography of atomic Nuclei

NR, A. Lovato, et al, 2606.14558

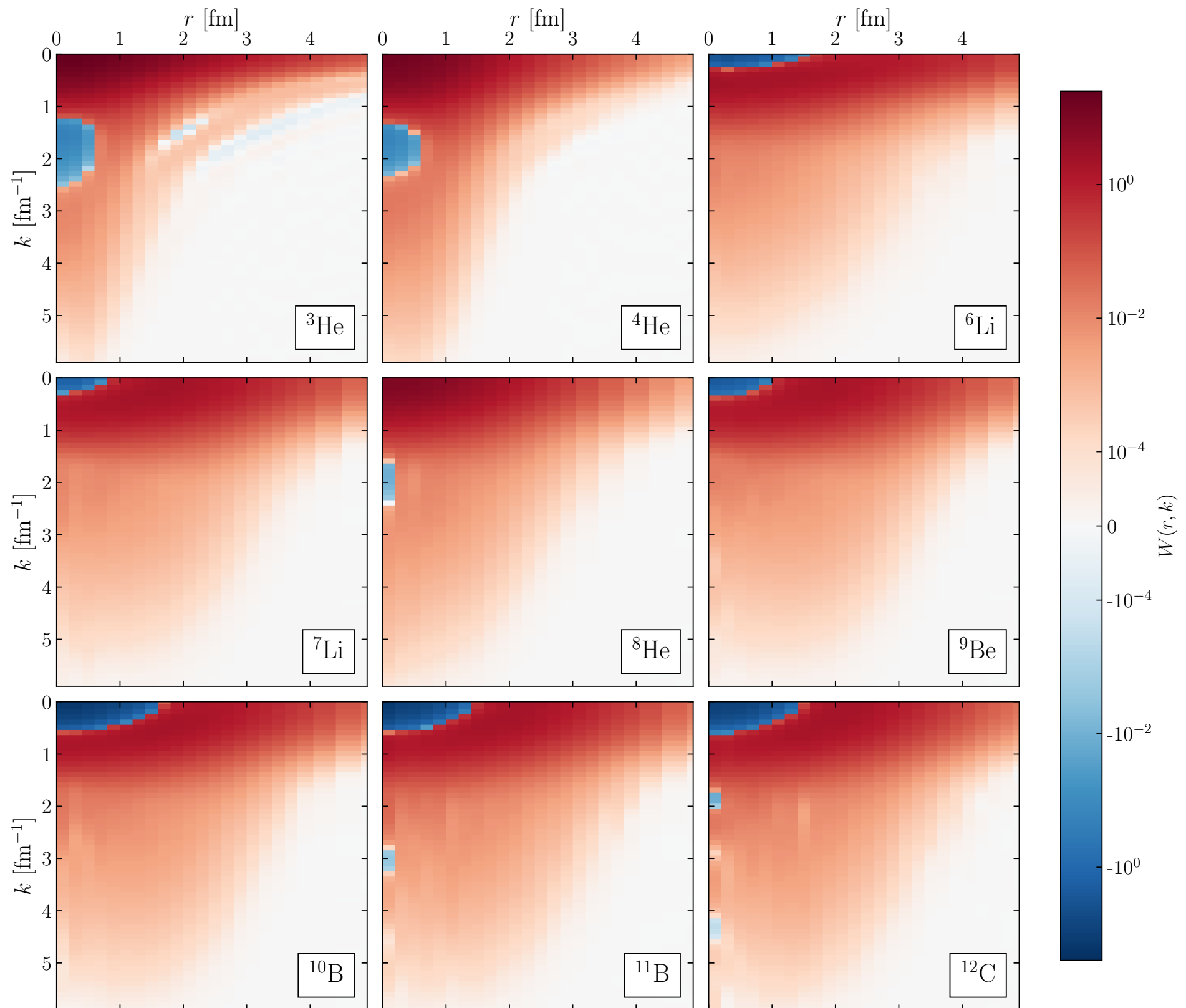
Wigner functions give the quasi-probability distribution of finding a nucleon with $\mathbf{k}$ and $\mathbf{r}$

$$W_N(\mathbf{R}, \mathbf{k}) = \int d\mathbf{s} e^{-i\mathbf{k}\cdot\mathbf{s}} \rho_N \left(\mathbf{R} + \frac{\mathbf{s}}{2}, \mathbf{R} - \frac{\mathbf{s}}{2} \right)$$
$$= A \int d\mathbf{s} d\mathbf{r}_2 \dots d\mathbf{r}_A, e^{-i\mathbf{k}\cdot\mathbf{s}} \Psi_0^* \left(\mathbf{R} - \frac{\mathbf{s}}{2}, \mathbf{r}_2, \dots, \mathbf{r}_A \right) P_{N(1)} \Psi_0 \left(\mathbf{R} + \frac{\mathbf{s}}{2}, \mathbf{r}_2, \dots, \mathbf{r}_A \right).$$

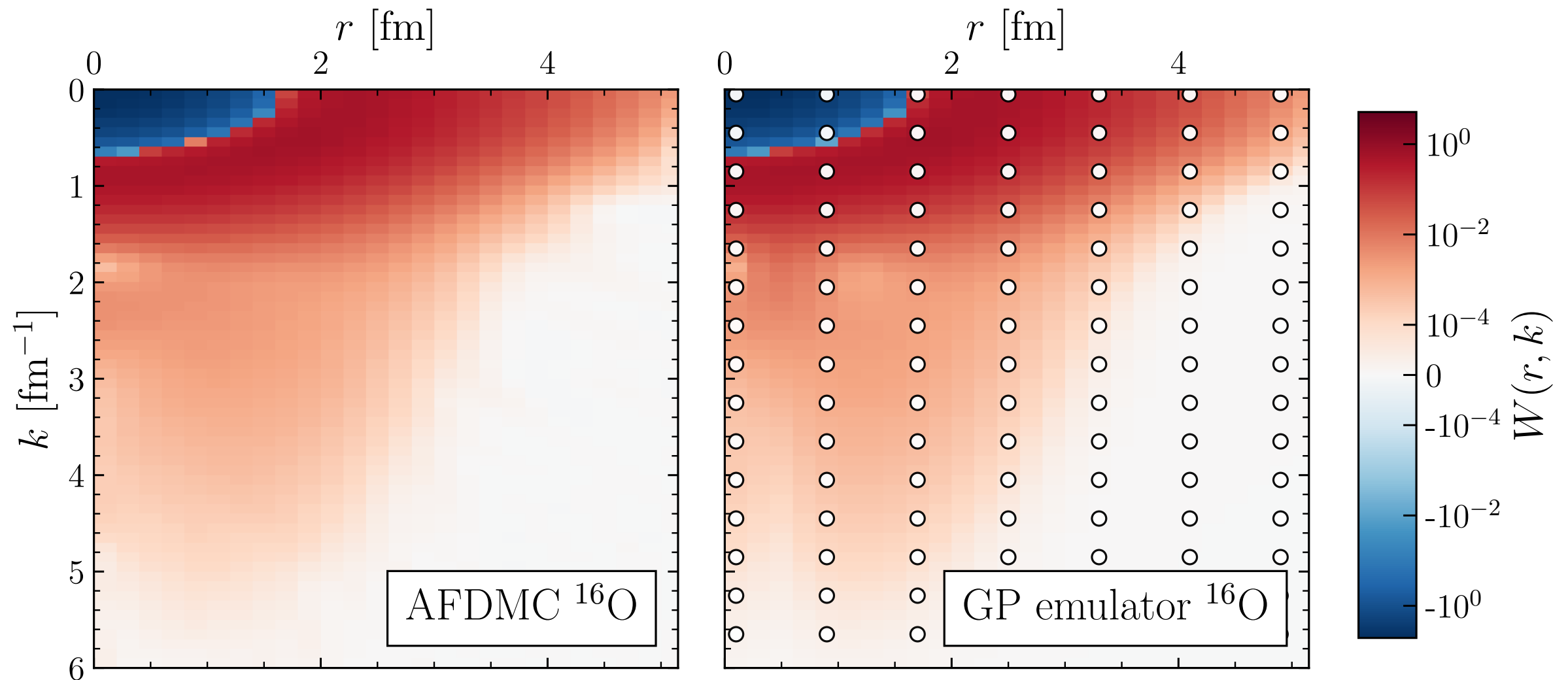


Tomography of atomic Nuclei

NR, A. Lovato, et al, 2606.14558



Tomography of atomic Nuclei



AFDMC results for ^{16}O compared with the GP-emulated distribution

GP emulators become helpful if we want to retain the full dependence on the relative orientation of $\mathbf{r}$ and $\mathbf{k}$ which requires a higher-dimensional representation

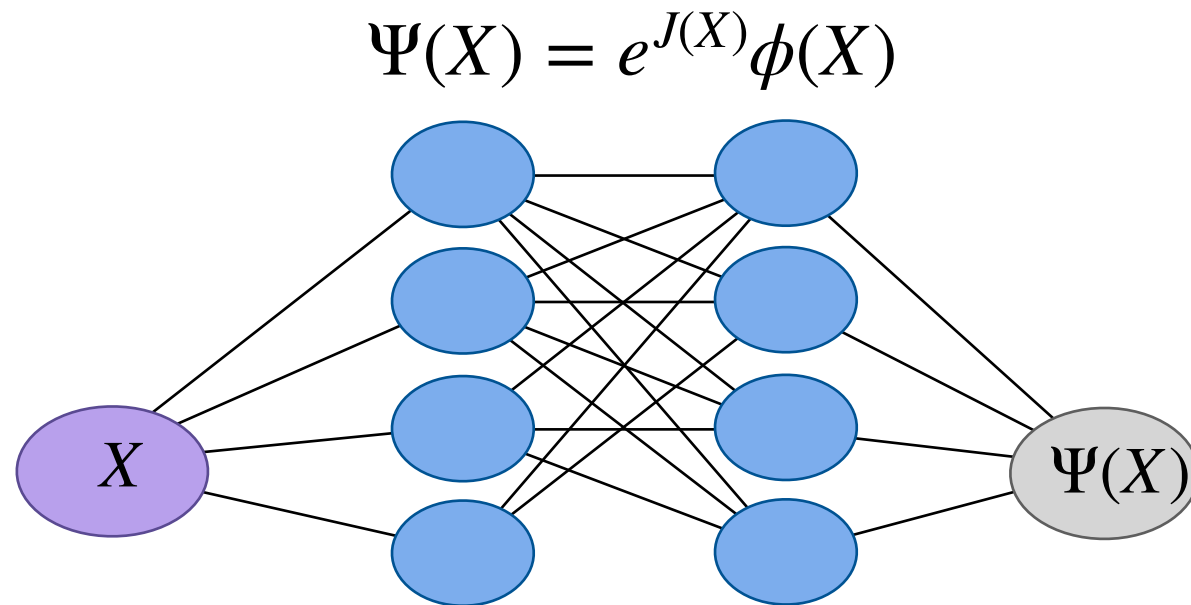
New perspectives: Neural Quantum States

A. Lovato, C. Adams, G. Carleo, NR, Phys.Rev.Res. 4 (2022) 4, 043178

A. Gnech, et al., Phys. Rev. Lett. 133 (2024) 14, 142501

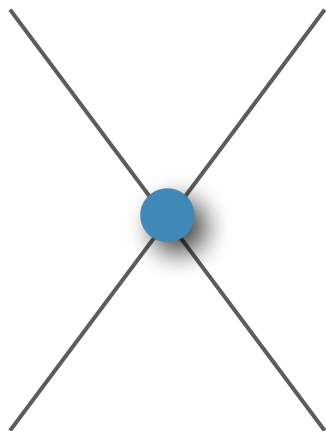
Best parameters are obtained using the **variational principle + stochastic reconfiguration**

$$E_V \equiv \frac{\langle \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} > E_0$$



See **A. Lovato's** talk
“Neural Quantum States for Dynamical Pions
and Nucleons”

Currently using LO pion-less EFT potential



- NN potential fit to s-wave np scattering lengths and effective ranges

$$v_{ij}^{\text{CI}} = \sum_{p=1}^4 v^p(r_{ij}) O_{ij}^p,$$

$$O_{ij}^{p=1,4} = (1, \tau_{ij}, \sigma_{ij}, \sigma_{ij} \tau_{ij})$$

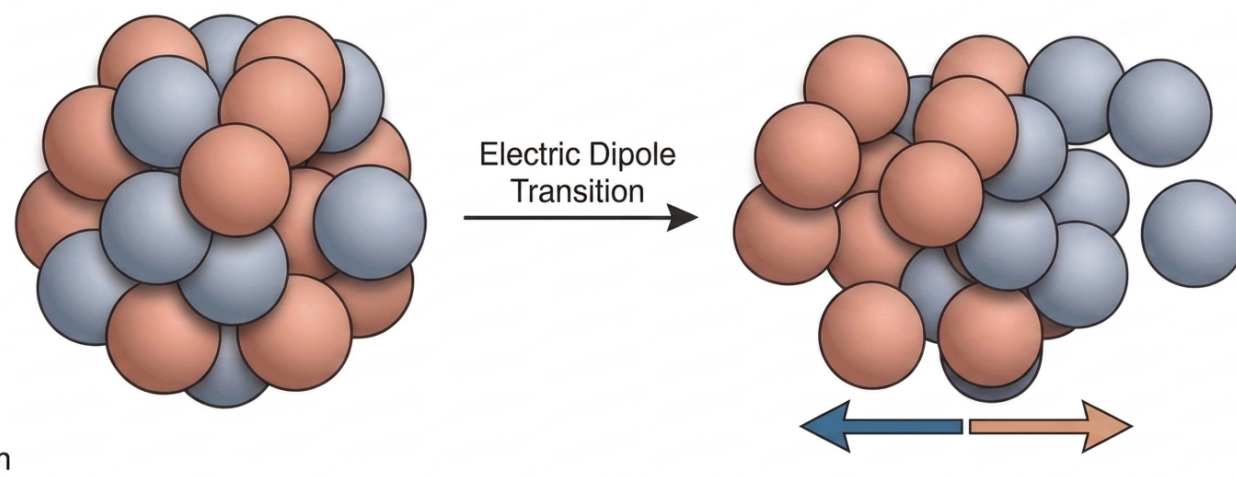
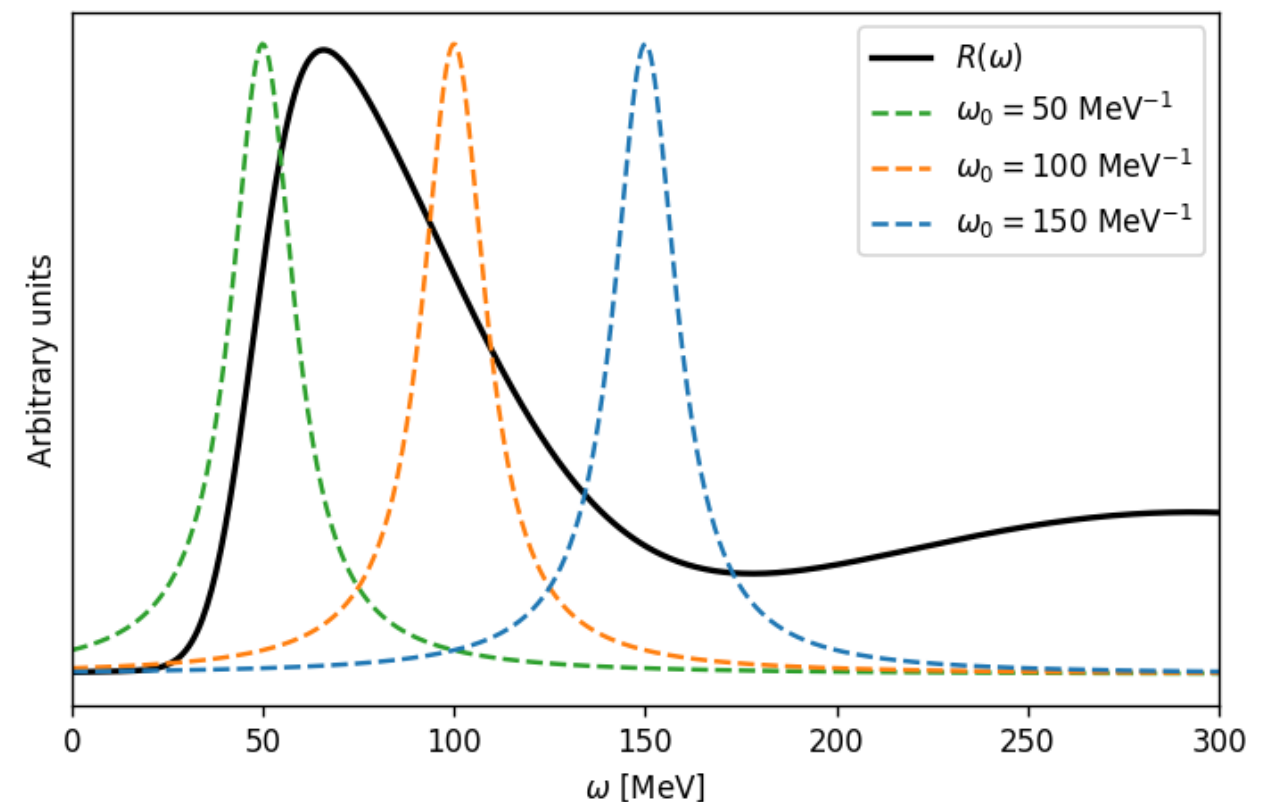
R. Schiavilla, A. Lovato, PRC 103, 054003 (2021)

Nuclear Responses with Neural Quantum States

$$R_{\alpha\beta}(\omega, \mathbf{q}) = \sum_f \langle 0 | J_{\alpha}^{\dagger}(\mathbf{q}) | f \rangle \langle f | J_{\beta}(\mathbf{q}) | 0 \rangle \delta(\omega - E_f + E_0)$$

We consider the Lorentz Kernel given by

$$L(\omega_0, \Gamma, \sigma) = \int d\omega \frac{1}{\pi} \frac{\Gamma R(\omega, \mathbf{q})}{\Gamma^2 + (\omega - \omega_0)^2}$$



Electric dipole transition:

$$J = \sum_i^A q_i (z_i - Z_{cm})$$

E. Parnes, NR, et al., Phys.Rev.Lett. 136 (2026) 3, 032501

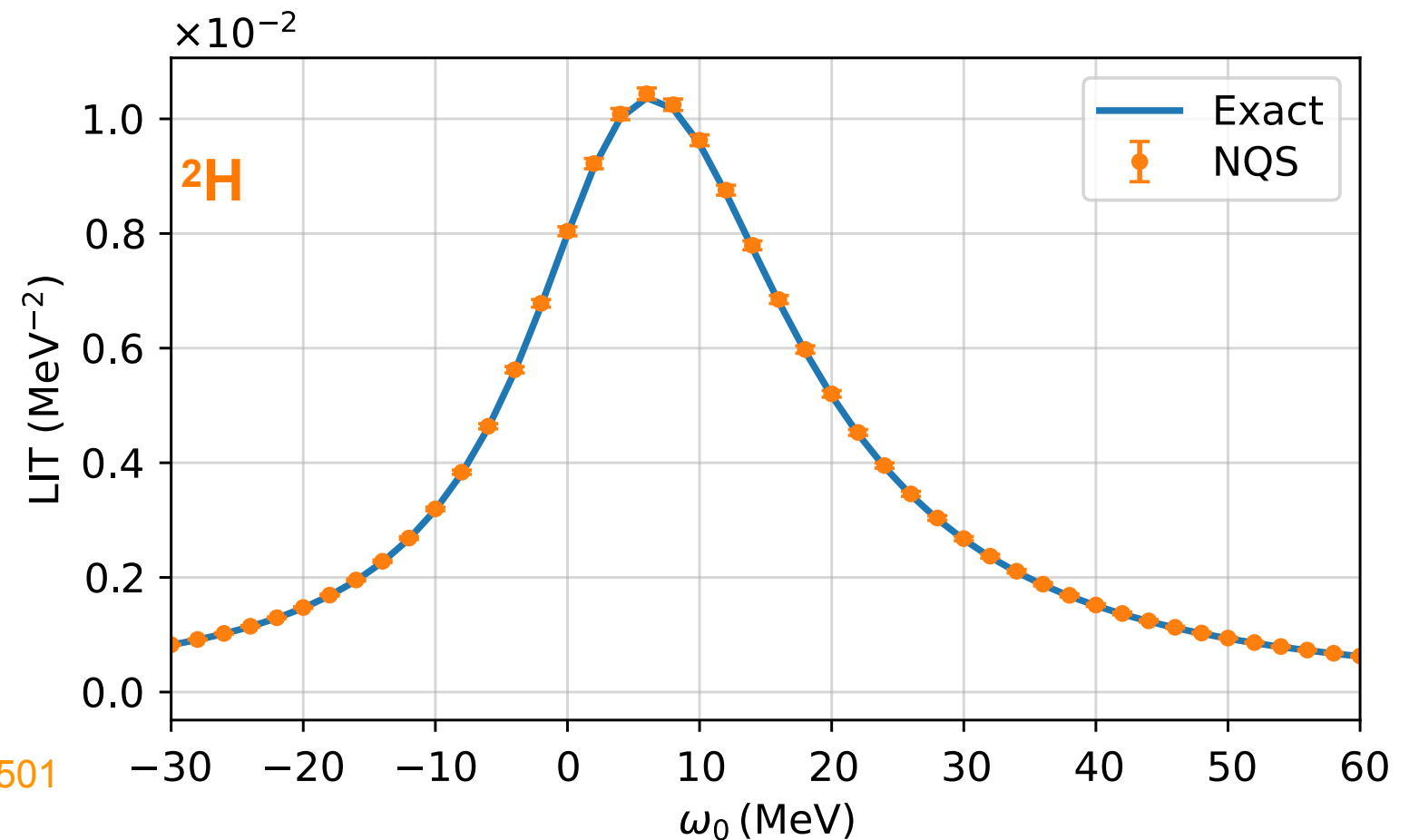
Nuclear Responses with Neural Quantum States

Ground-state expectation value:

$$L(\omega_0, \Gamma, \mathbf{q}) = \langle \Psi_0 | J^\dagger \frac{1}{H - E_0 - \omega_0 + i\Gamma} \frac{1}{H - E_0 - \omega_0 - i\Gamma} | \Psi_0 \rangle$$

Resolvent equation:

$$(H - E_0 - \omega_0 - i\Gamma) | \Psi_L \rangle = J | \Psi_0 \rangle$$



E. Parnes, NR, et al., Phys.Rev.Lett. 136 (2026) 3, 032501

1) Maximize the fidelity

$$\mathcal{F}(\Psi, \Phi) = \frac{\langle \Psi | \Phi \rangle \langle \Phi | \Psi \rangle}{\langle \Psi | \Psi \rangle \langle \Phi | \Phi \rangle}$$

$$\left\{ \begin{array}{l} |\Psi\rangle = (\hat{H} - E_0 - \omega_0 + i\Gamma) |\Psi_L\rangle \\ |\Phi\rangle \equiv J |\Psi_0\rangle \end{array} \right.$$

New techniques to invert the LIT

To obtain the parameters, we use an improved version of the maximum-entropy approach

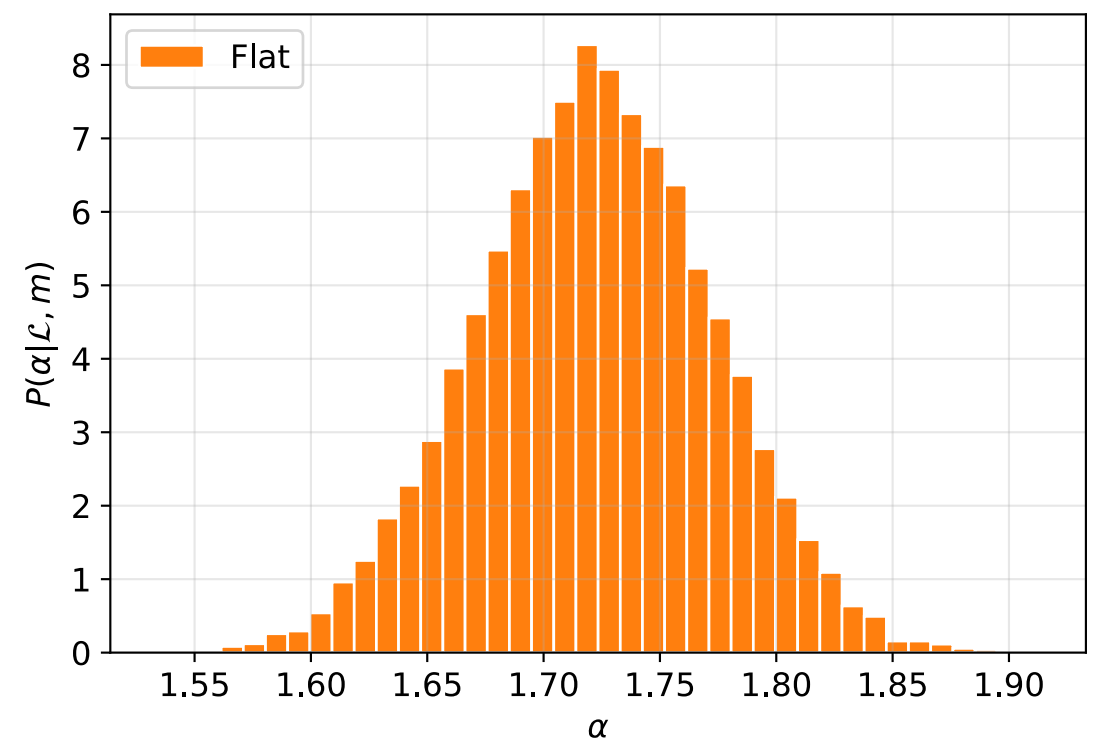
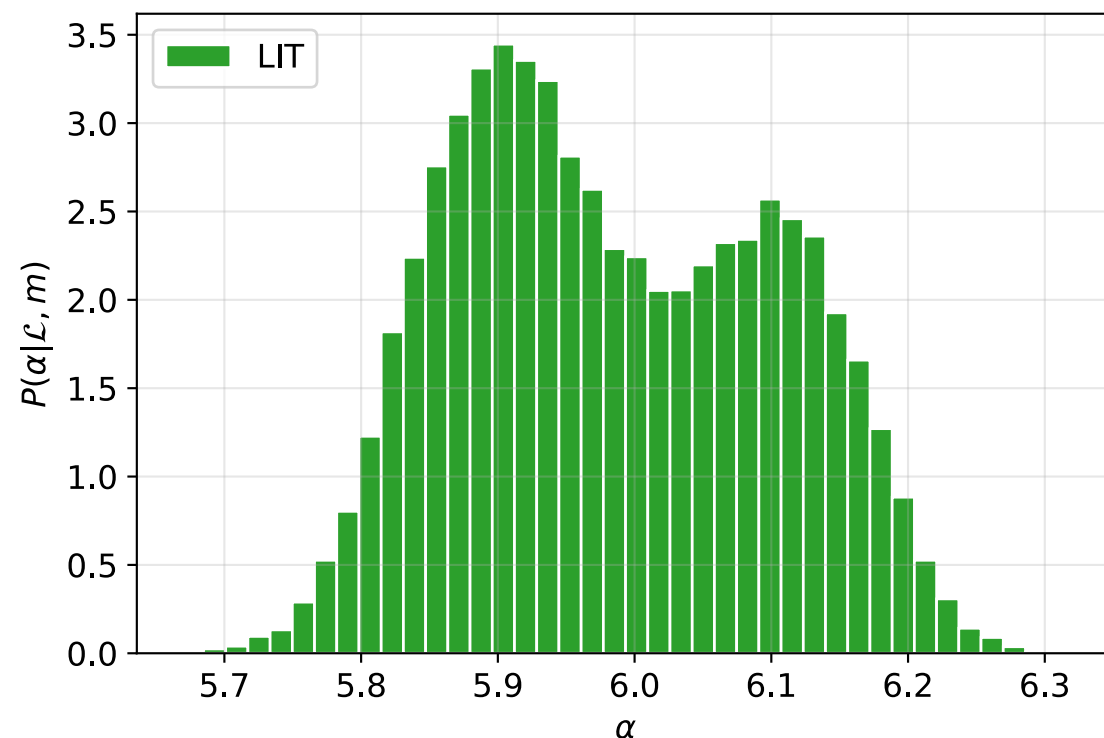
I want to maximize the conditional probability

$$P(R | \mathcal{L}) = P(\mathcal{L} | R) \frac{P(R)}{P(\mathcal{L})},$$

The likelihood function is $P(\mathcal{L} | R) = \frac{e^{-\chi^2/2}}{Z_L}$

Entropic prior (Skilling) $P(R | m, \alpha) = \frac{e^{\alpha S}}{Z_S} \simeq \frac{1}{Z_S} \exp \left\{ \alpha \sum_{i=1}^{N_\omega} \left[R_i - m_i - R_i \log \left(\frac{R_i}{m_i} \right) \right] \right\},$

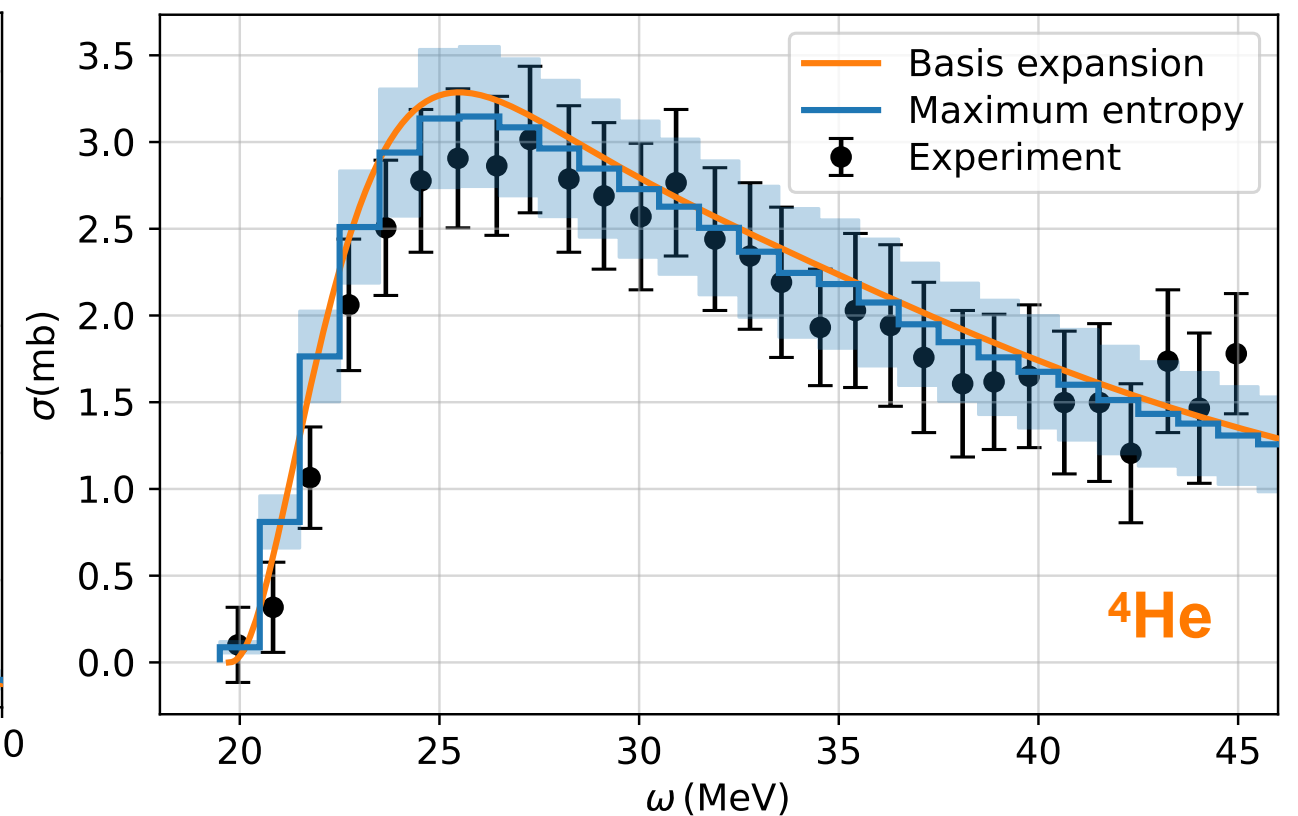
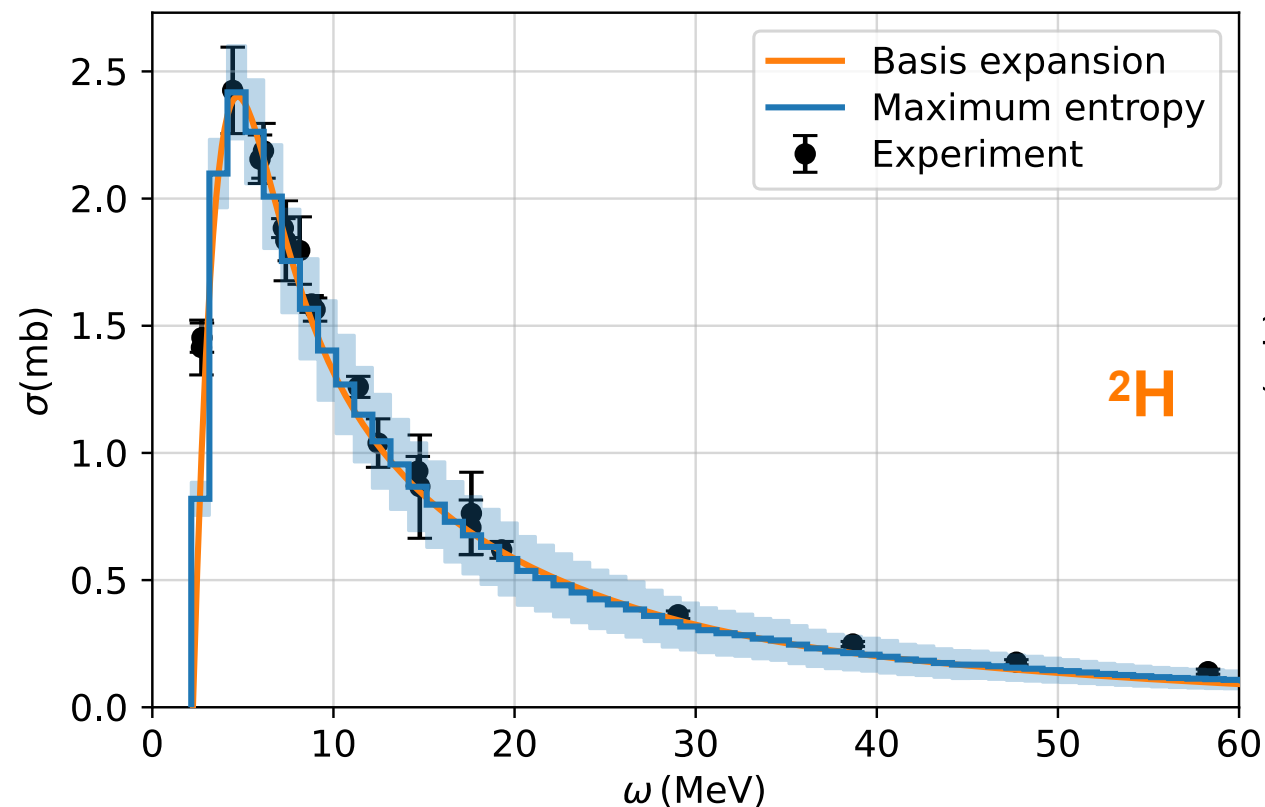
MCMC “with swap” used to sample the posterior: no need to fix α



Nuclear Responses with Neural Quantum States

Computed the photo-absorption cross section with quantified uncertainties

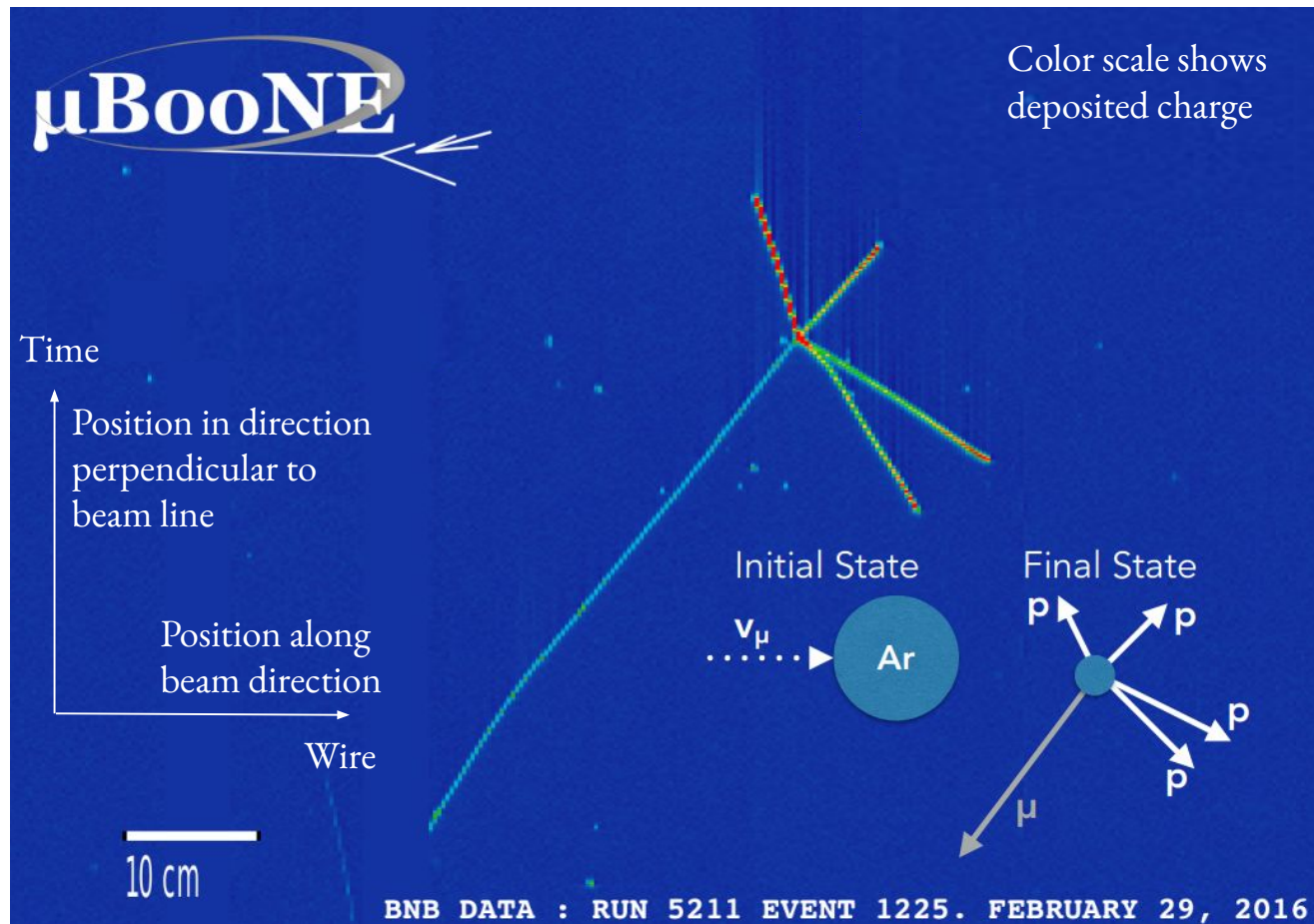
E. Parnes, NR, et al., Phys.Rev.Lett. 136 (2026) 3, 032501



First usage of NQS to compute dynamical observables

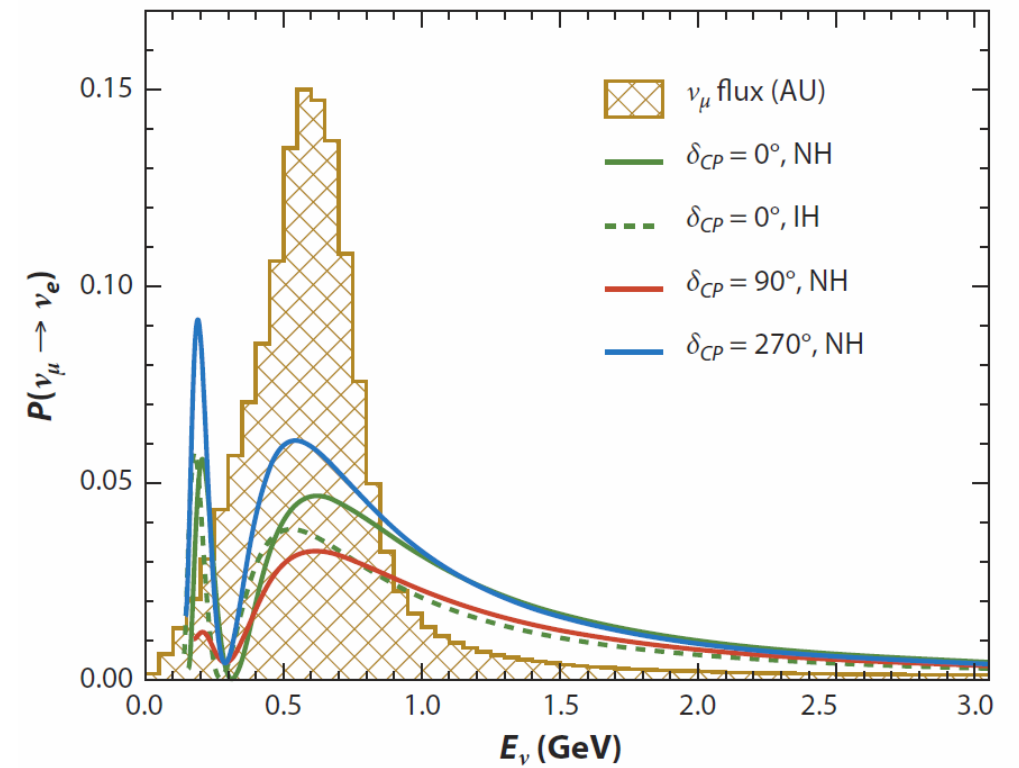
Extend this formalism to perform real-time dynamics which will be used for neutrino responses

Address new experimental capabilities

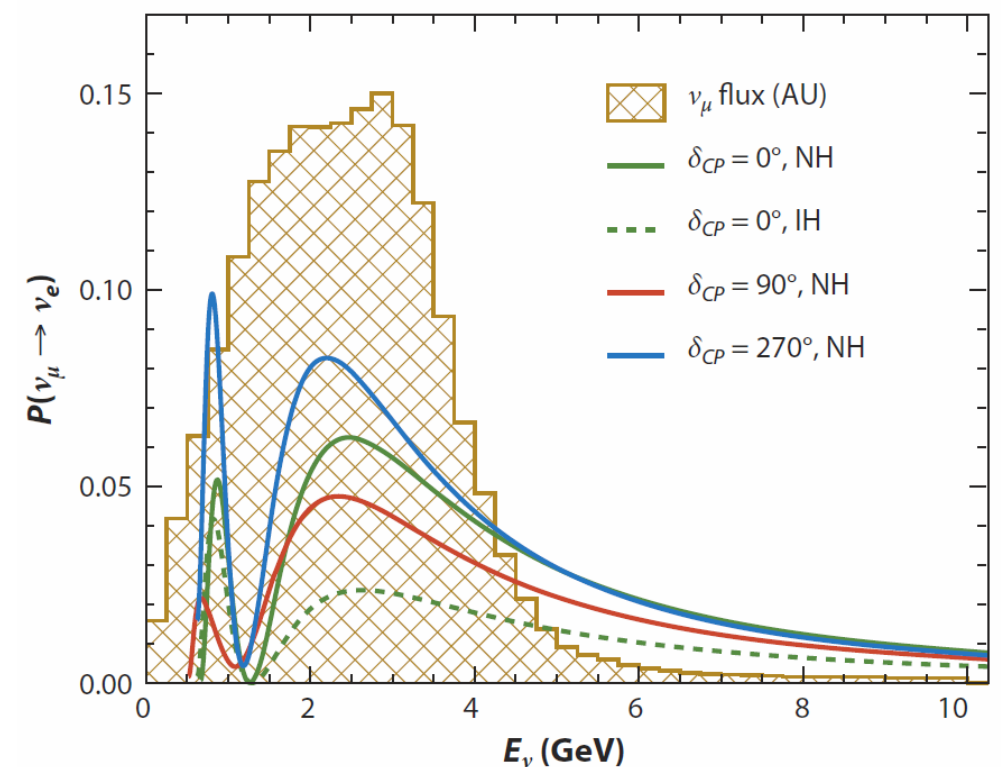


- Excellent spatial resolution
- Precise calorimetric information
- Powerful particle identification

T2K / HyperK Flux



DUNE Flux



From theory to measurement

$$d\sigma(\nu A) \approx$$

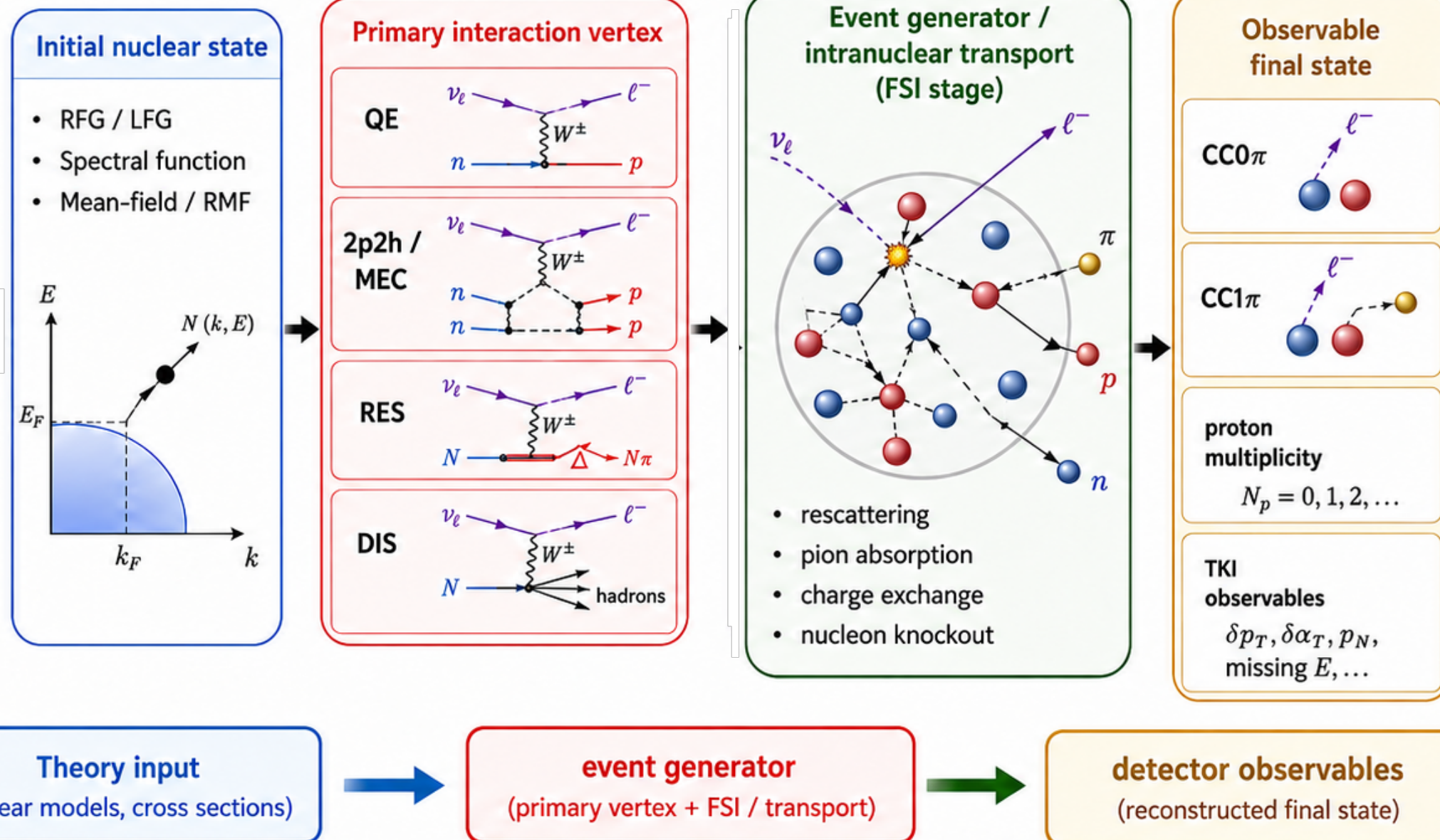
Initial-state model



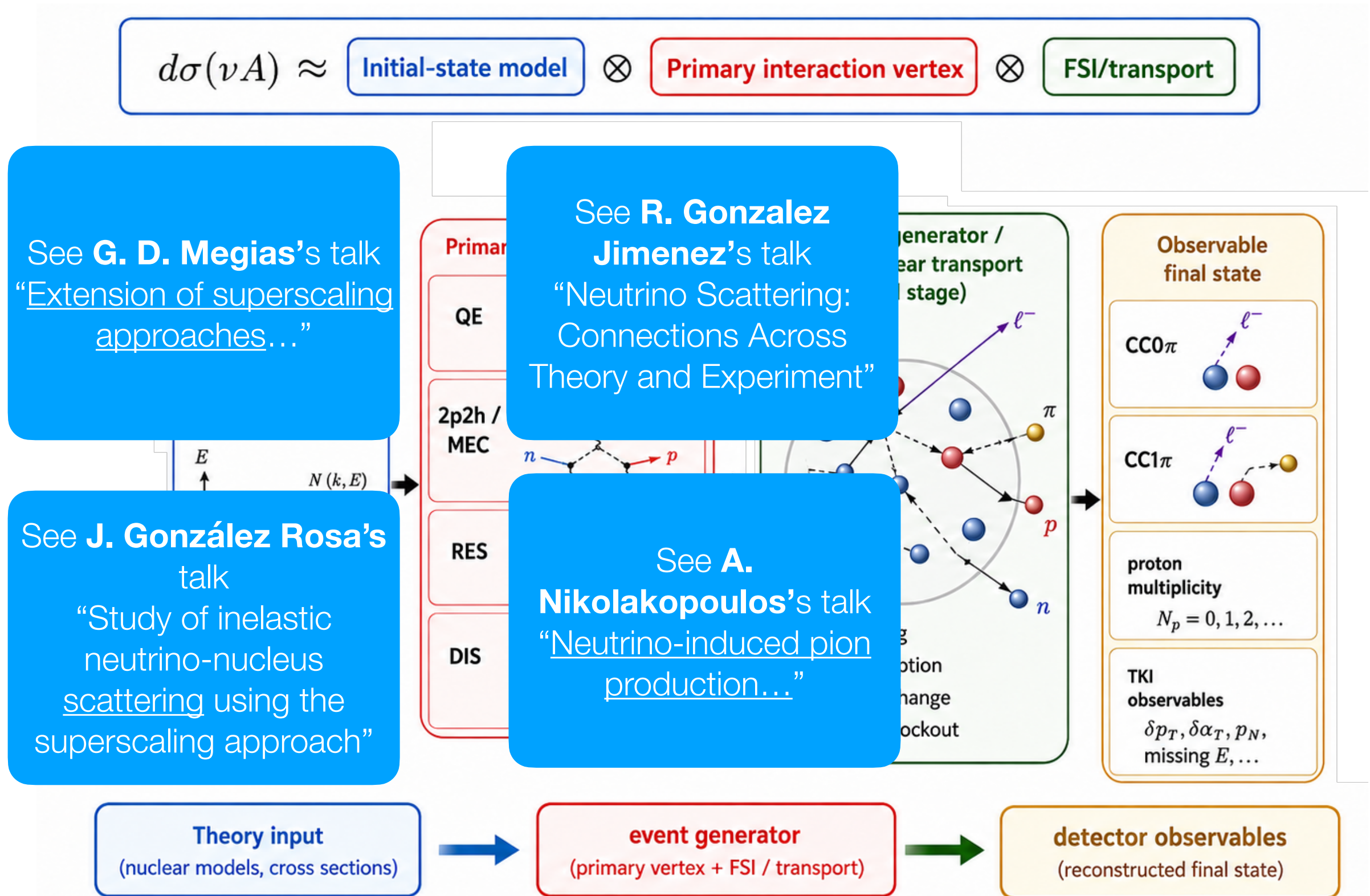
Primary interaction vertex



FSI/transport



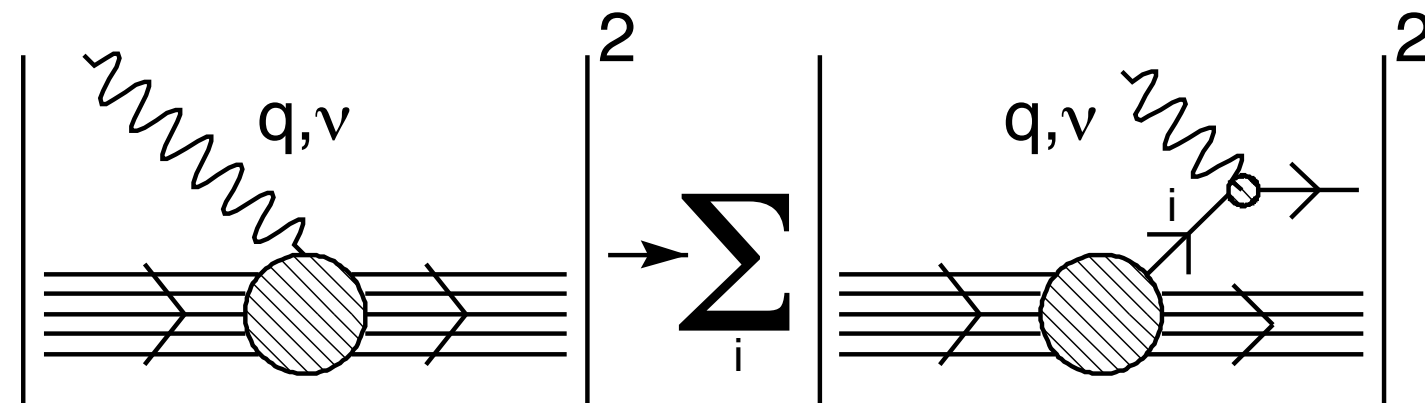
From theory to measurement



Spectral function approach

The response tensor is given by

$$R^{\mu\nu}(\mathbf{q}, \omega) = \int d^3k dE P_h(\mathbf{k}, E) \frac{m_N^2}{e(\mathbf{k})e(\mathbf{k} + \mathbf{q})} \sum_i \langle k | j_i^{\mu\dagger} | p \rangle \langle p | j_i^\nu | k \rangle \delta(\omega + E - e(\mathbf{k} + \mathbf{q}))$$



The nuclear cross section is replaced by the incoherent sum of cross sections describing scattering off individual nucleons, the recoiling $(A - 1)$ -nucleon system acting as a spectator.

The spectral function gives the probability density of finding nucleon $(\mathbf{k}, E)$ in ground state nucleus

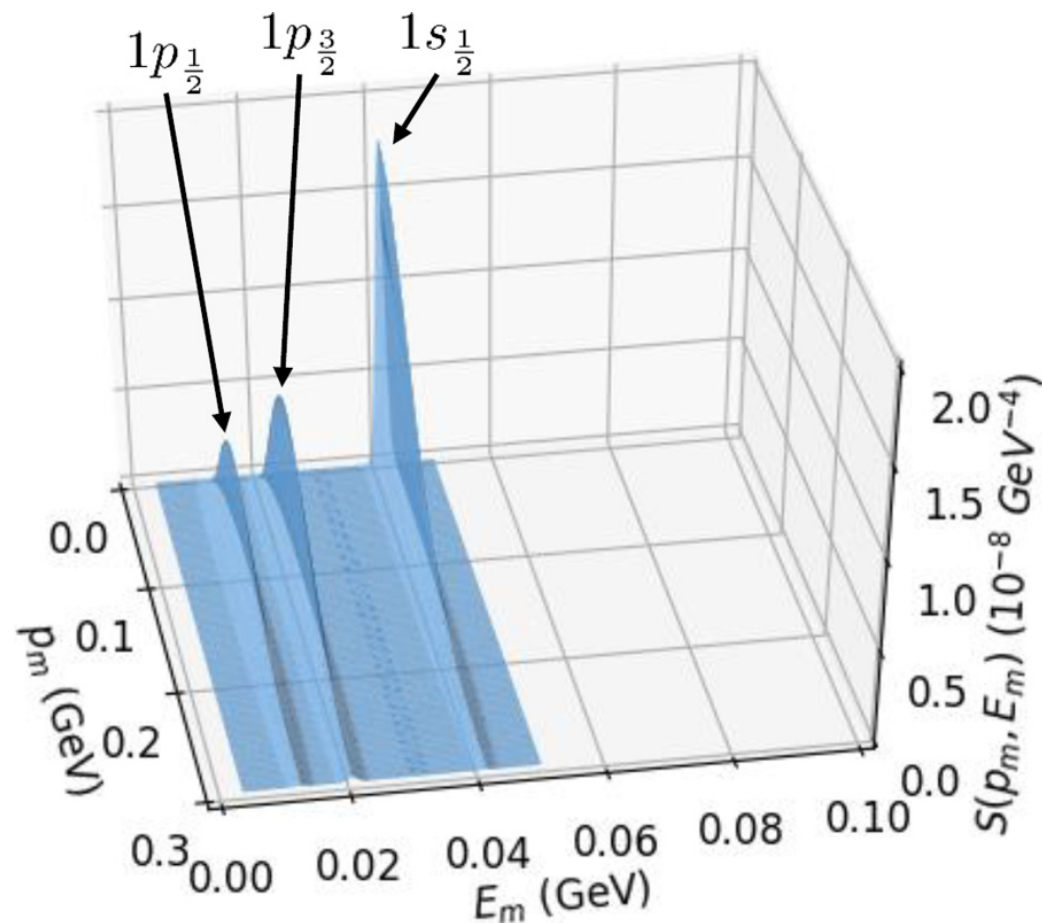
Spectral function from Quantum Monte Carlo

CLAS collaboration NR et al, PRC 107 (2023) 6, L061301

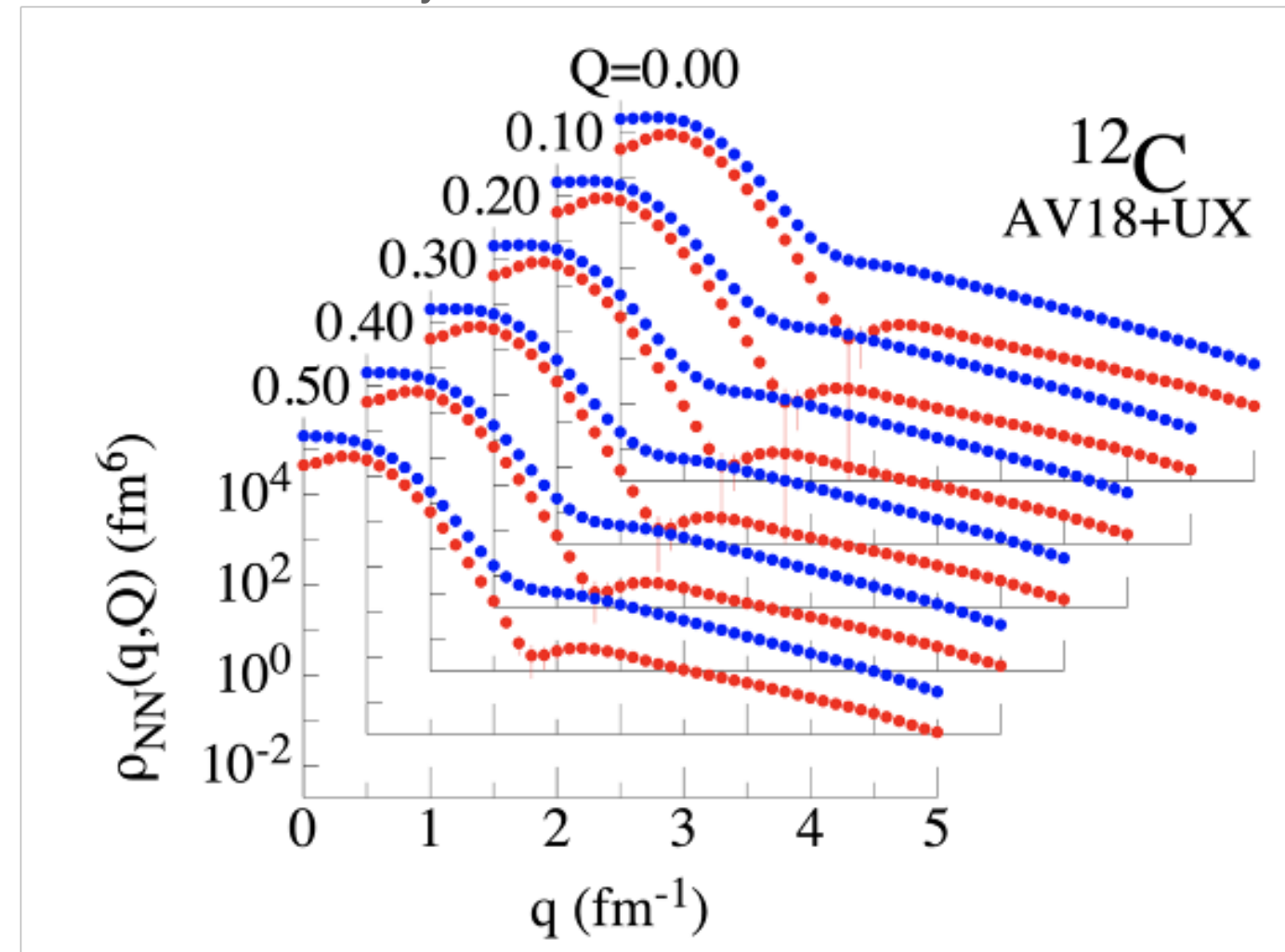
The nucleon spectral function describe intrinsic properties of the initial nucleus:

$$P_{p,n}(\mathbf{k}, E) = \sum_n \left| \langle \Psi_0^A | [|k\rangle \otimes | \Psi_n^{A-1} \rangle] \right|^2 \delta(E + E_0^A - E_n^{A-1}) = P^{MF}(\mathbf{k}, E) + P^{\text{corr}}(\mathbf{k}, E)$$

Single-nucleon overlaps



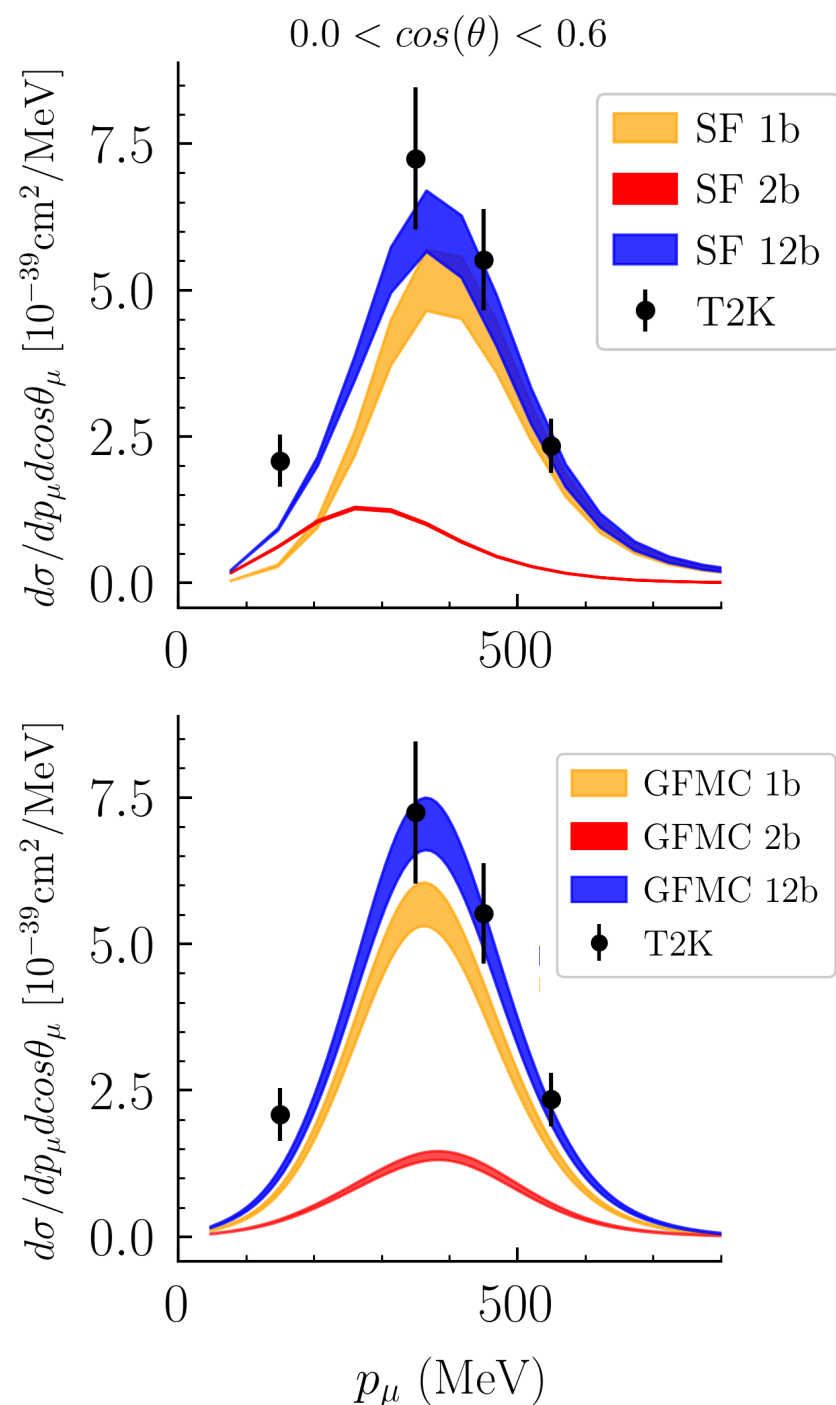
Two-body momentum distributions



Wiringa, et al., Phys. Rev. C 89, 024305 (2014)

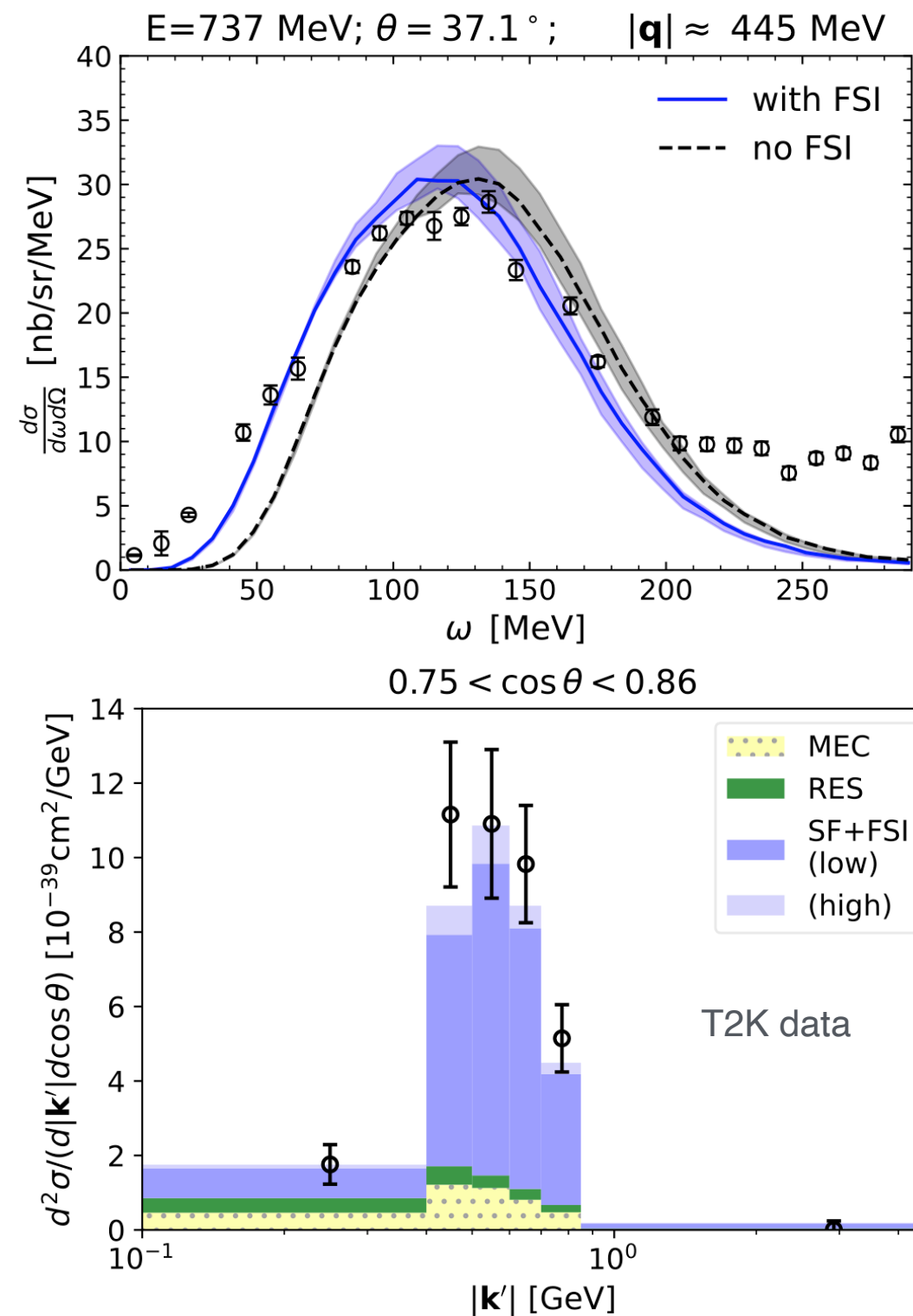
Spectral function: from ab-initio techniques

Quantum Monte Carlo - Spectral Function



A.Lovato, NR et al, Universe 9 (2023) 8, 367

Coupled-Cluster - Spectral Function

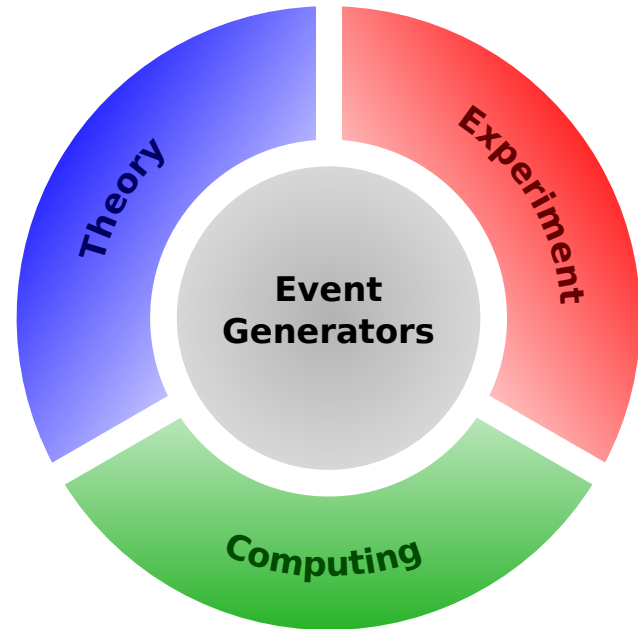


J.E. Sobczyk, PRC 109, 044314 (2024)

Event Generators

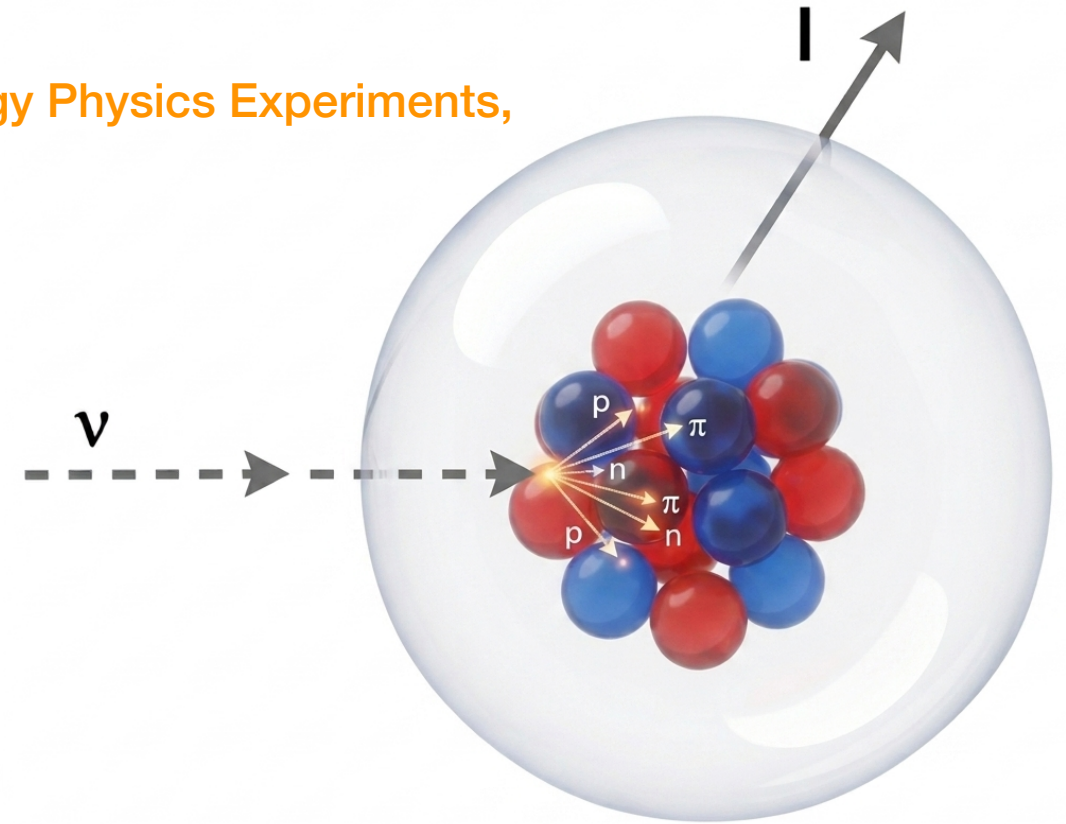
The propagation of **hadrons** through the nuclear medium is crucial in the analysis of neutrino oscillation experiments.

Event Generators for High-Energy Physics Experiments,
2022 Snowmass Summer Study



Event generators are also used to predict **backgrounds** and **efficiency**

Different generators currently available:



See **L. Munteanu**'s talk
"Characterising the role of final state
Interactions..."

See **S. Abe**'s talk
"Simulation of single-pion production...in
NEUT"

Achilles: A CHicagoLand Lepton Event Simulator

Core Authors



Graduate Students



Undergraduates - Former Contributors



Achilles: Hard Interaction Vertex

$$E_e = 2222 \text{ MeV}$$

$$\theta_{e'} = 15.541^\circ$$

- We use the SF formalism to describe QE + pion production
- Hadron momenta and isospins as well as momentum transfer provide inputs to DCC code

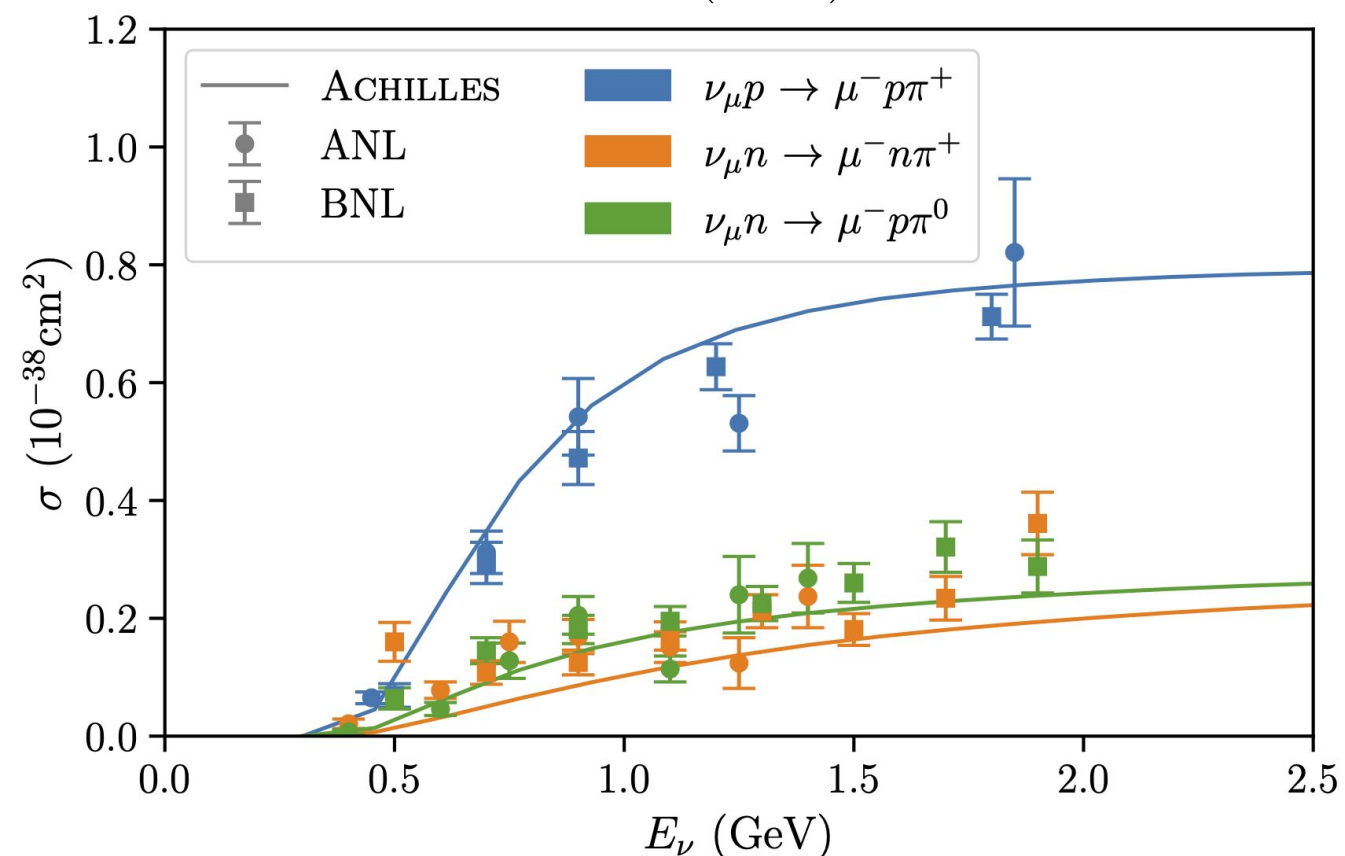
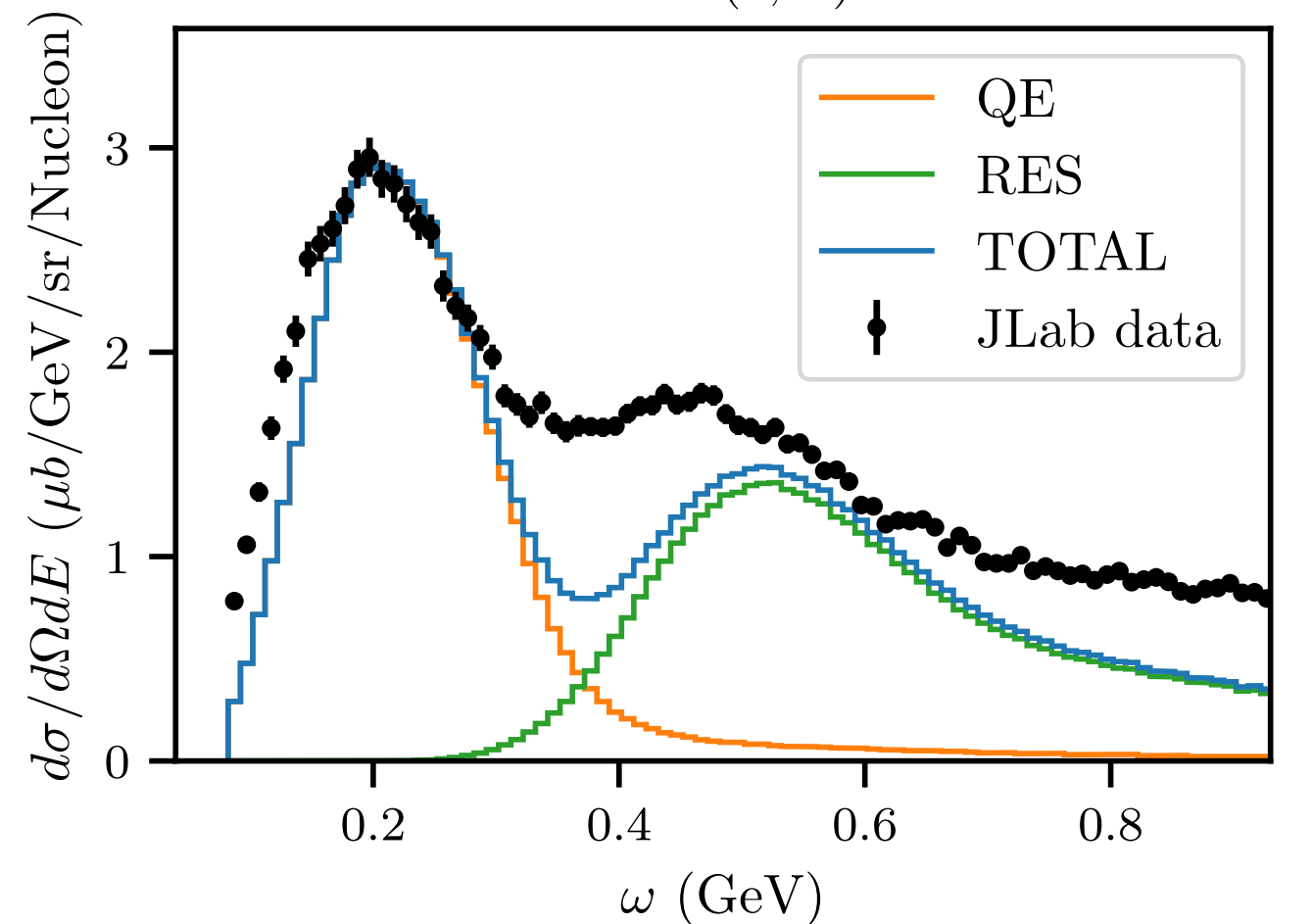
See T. Sato's talk
[“ANL-Osaka Model for extracting nucleon resonances”](#)

- Inclusive comparisons validate DCC model and its implementation in Achilles

Reproduces (e,e') JLab data in the Delta region

ANL and BNL comparison validate DCC model's axial current

[J. Isaacson, NR, et al, Phys.Rev.D 113 \(2026\) 3, 036005](#)



Intranuclear cascade: Pions

[J. Isaacson, NR, et al, Phys.Rev.D 113 \(2026\) 3, 036005](#)

Simulate pion physics in the nucleus requires evaluation of a number of processes.

Initial States	Final States	
	Virtual Resonances	Propagating Resonances
NN	$NN, NN\pi$	$NN, N\Delta(\rightarrow NN\pi, NN\gamma)$
πN	$\pi N, \eta N, K\Lambda, K\Sigma$	$\Delta(\rightarrow \pi N, \gamma N)$
ηN	$\pi N, \eta N, K\Lambda, K\Sigma$	Initial state not present
ΔN	Initial state not present	$NN, \Delta N$
πNN	NN (s - and p -wave)	$\Delta N(\rightarrow NN), NN$ (s -wave)

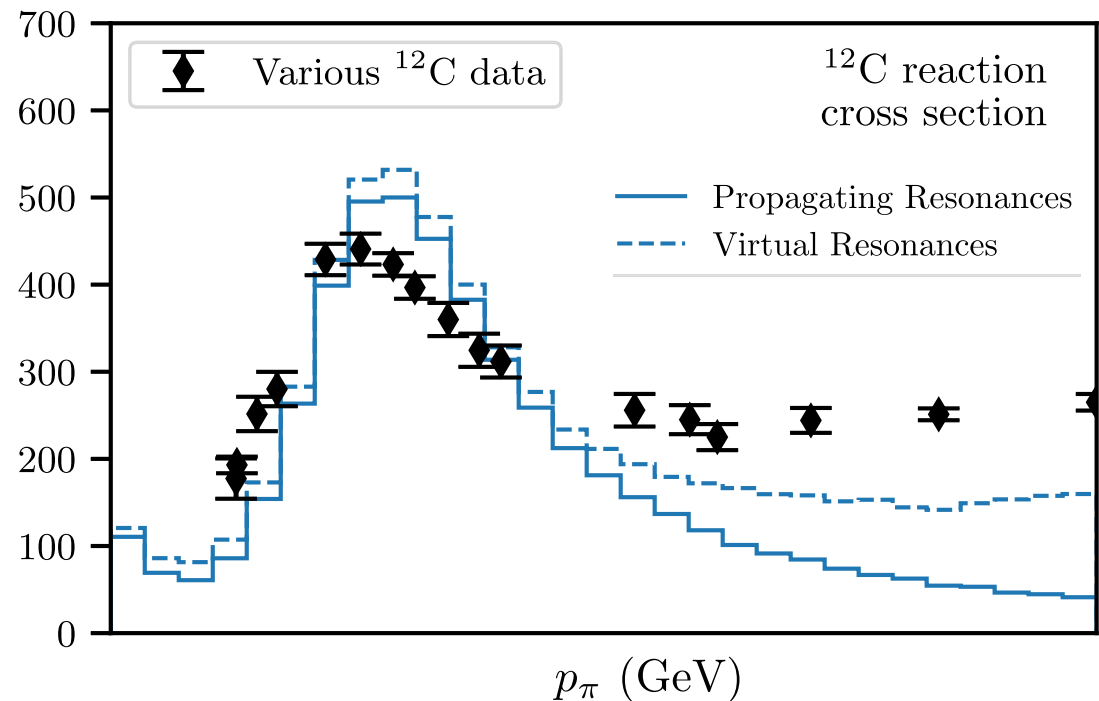
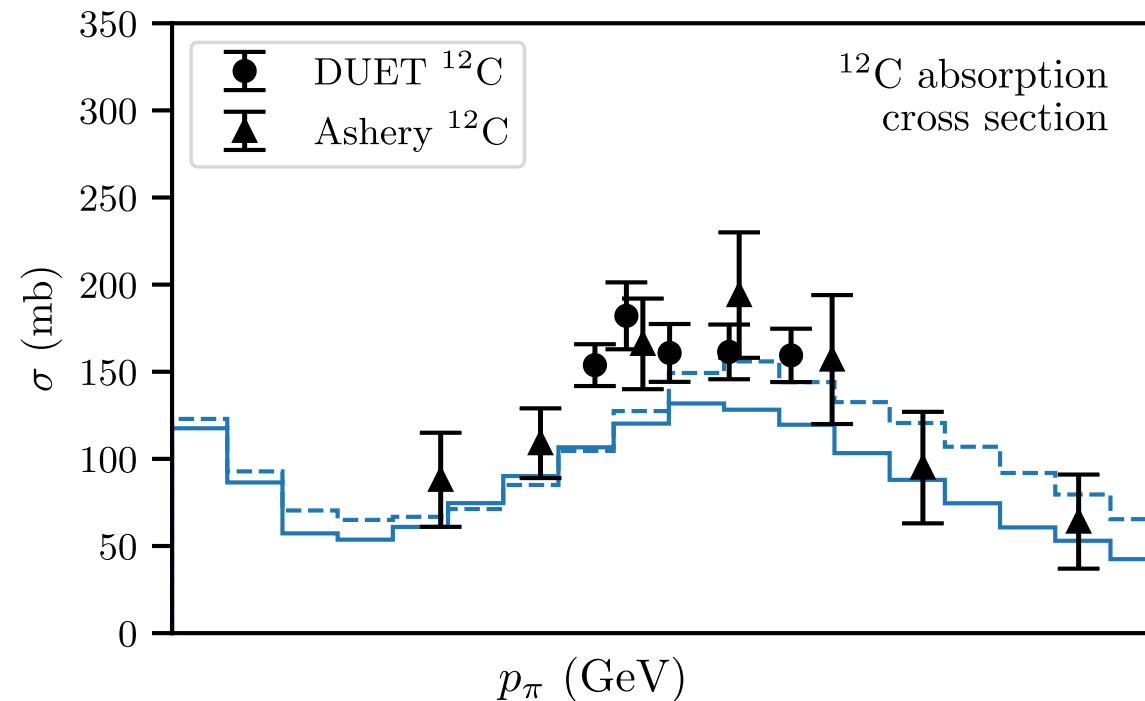
Quantum mechanical effects that are relevant:

Interference between resonant and non resonant terms

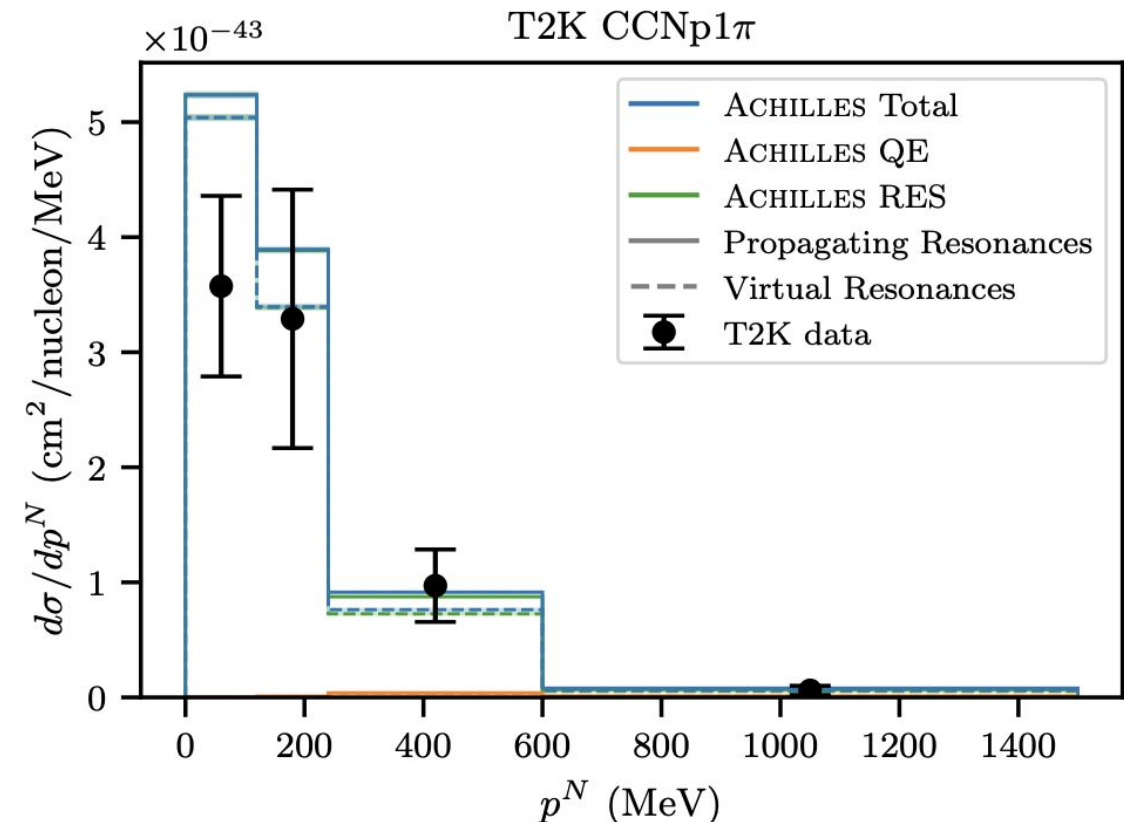
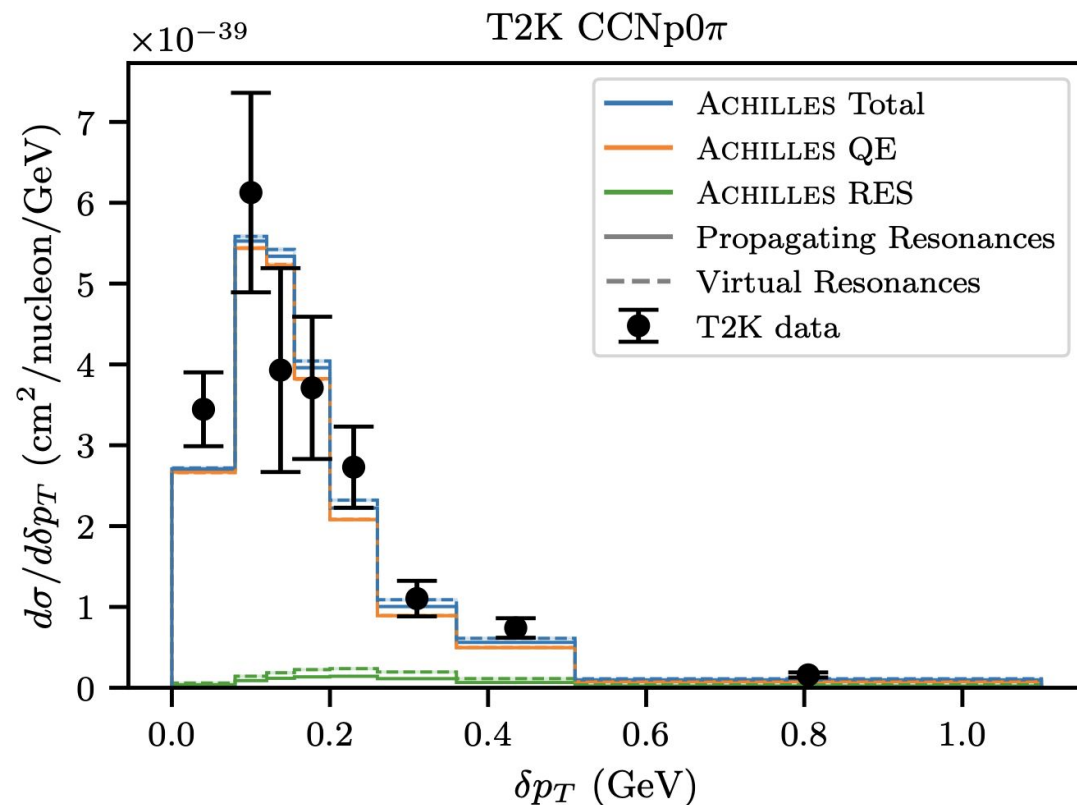
Long lifetime of resonances

Impossible combine all the requirements with one model. Use the differences between models as an uncertainty estimate

Achilles: incorporating pion degrees of freedom



- Comparison with T2K data including π absorption and re-scattering



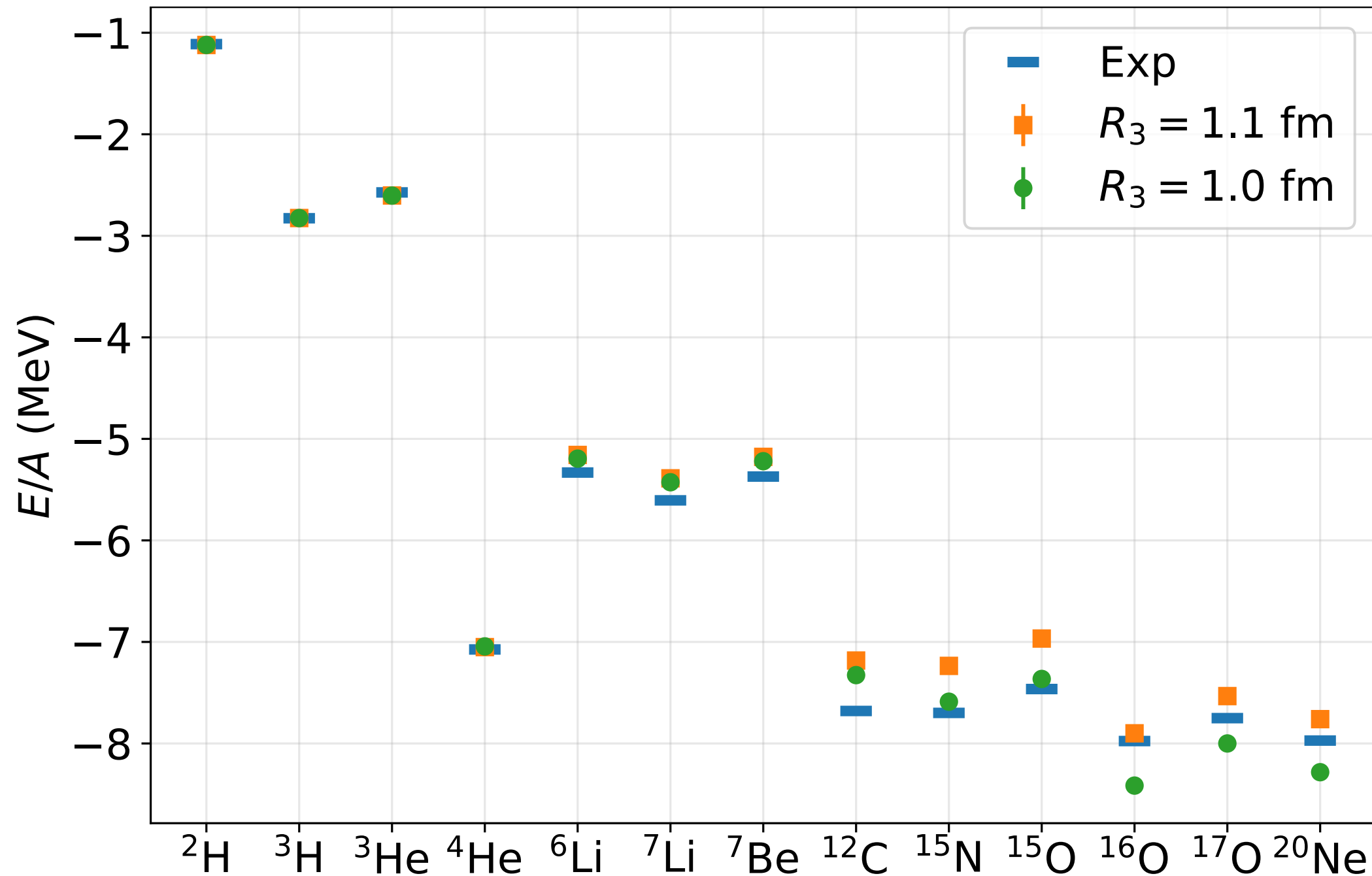
Conclusions and outlook

- ✓ Oscillation experiments are entering a precision era: need for neutrino-nucleus interactions
- ✓ Continuum QMC methods allow for a multi-scale description of atomic nuclei, including:
 - ✦ Response functions: studies of relativity and form factors
 - ✦ Wigner quasi-probability distributions.
 - ✦ Spectral functions
- ✓ Neural Quantum States: first applications to dipole responses and future directions
- ✓ Factorized approaches extend to high energies and exclusive channels
- ✓ Event generators are implementing new models and improving π physics

Thank you for your attention

Thank you for your attention!

Neural Network Quantum States up to $A=20$

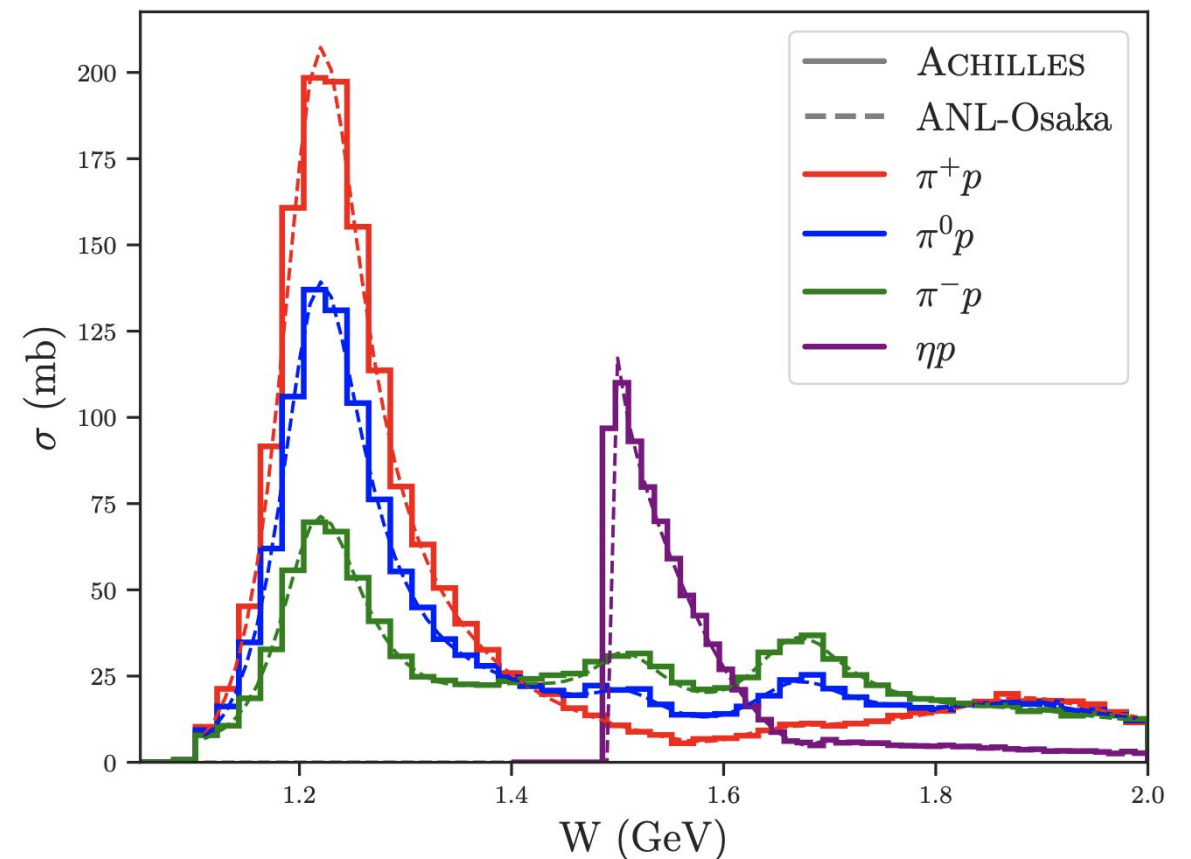


A. Gnech, et al., Phys. Rev. Lett. 133 (2024) 14, 142501

Virtual Resonances model

Parametrize $\pi N \rightarrow \text{MB}$ transitions using
partial waves amplitudes from **DCC model**

Accounts for interference between resonant and
non-resonant amps in angular distributions

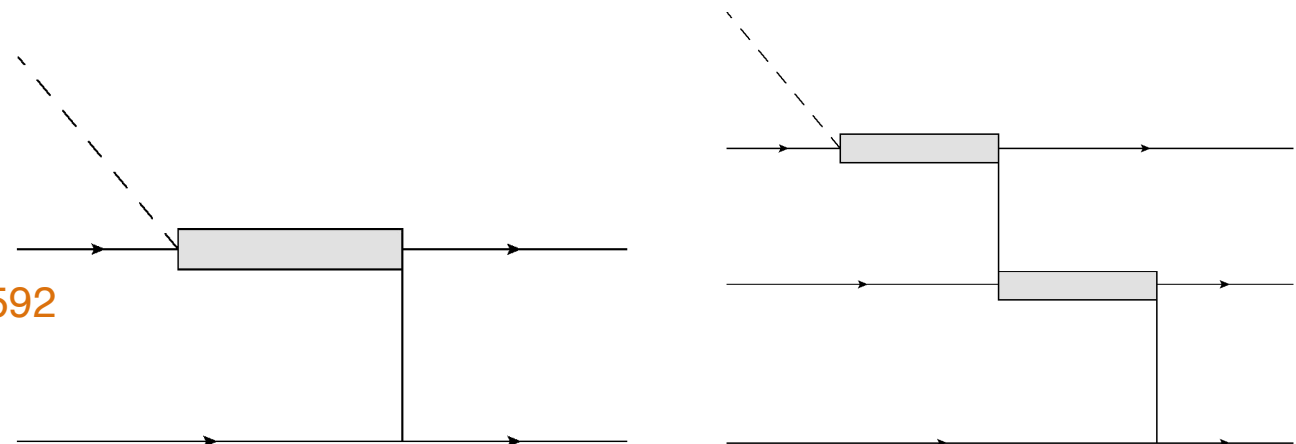


Use the Oset-Salcedo prescription for pion-absorption using pion-nucleus optical potential

$$\sigma_{\text{abs}} = -\frac{1}{q} \Im \Pi_{\text{abs}}(q^0, \mathbf{q})$$

Modify to the delta self energy due to P.B. and quasielastic scattering

Oset, Salcedo et al. Nucl.Phys.A 484 (1988) 557-592



Propagating Resonances model

Propagates and decay resonances following model implemented in GiBUU and INCL

πN interactions are always mediated by a Δ in a two-step process

$$\pi N \rightarrow \Delta$$

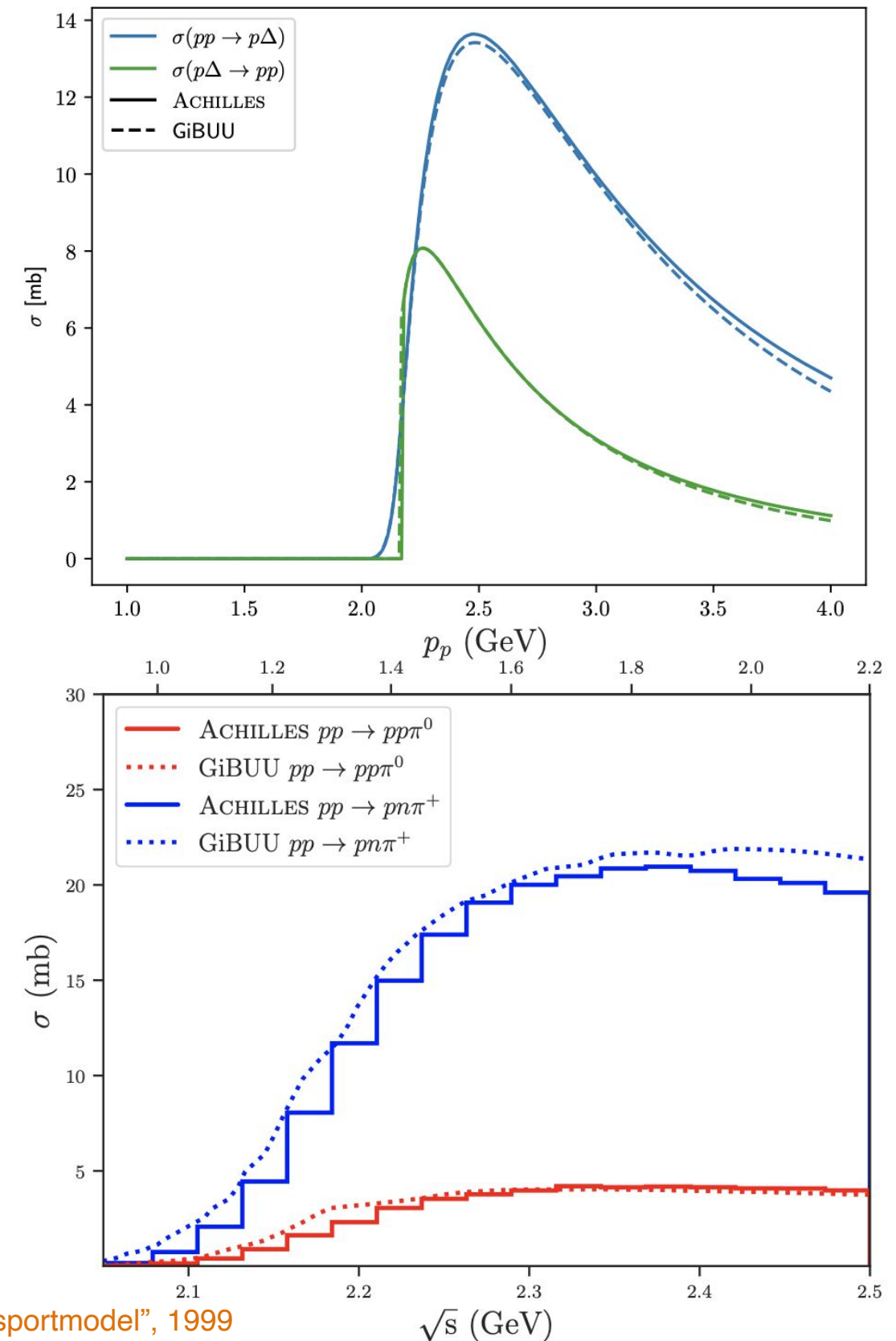
- $\Delta N \rightarrow \Delta N$
- $\Delta N \rightarrow NN$
- $\Delta \rightarrow \pi N$

At each step the decay probability is evaluated

$$P(t) = 1 - e^{\delta t/\tau}$$

Detailed balance is used to relate the channels

$$\Delta N \rightarrow NN, NN \rightarrow N\Delta$$



Buss, "Photon- and Pion-induced Reactions in a Transport Approach, 2008

Effenberger, "Eigenschaften von Hadronen in Kernmaterie in einem vereinheitlichten Transportmodell", 1999

Noemi Rocco, IFIC UV/CSIC Valencia

Stochastic Reconfiguration

The ANN is trained by minimizing the energy expectation value

$$\frac{\langle \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} = E_V \geq E_0$$

We supplement the gradient of the energy using a quantum Fisher information pre-conditioner

$$G_i = 2 \left(\frac{\langle \partial_i \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} - E_V \frac{\langle \partial_i \Psi_V | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} \right); \quad S_{ij} = \frac{\langle \partial_i \Psi_V | \partial_j \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} - \frac{\langle \partial_i \Psi_V | \Psi_V \rangle \langle \Psi_V | \partial_j \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle \langle \Psi_V | \Psi_V \rangle}$$

During the optimization, then parameters at step s are updated as

$$p^{s+1} = p^s - \eta (S + \epsilon I)^{-1} G$$

Imaginary-time evolution in the variational manifold



Natural Gradient descent

Relevant Inputs from AFDMC

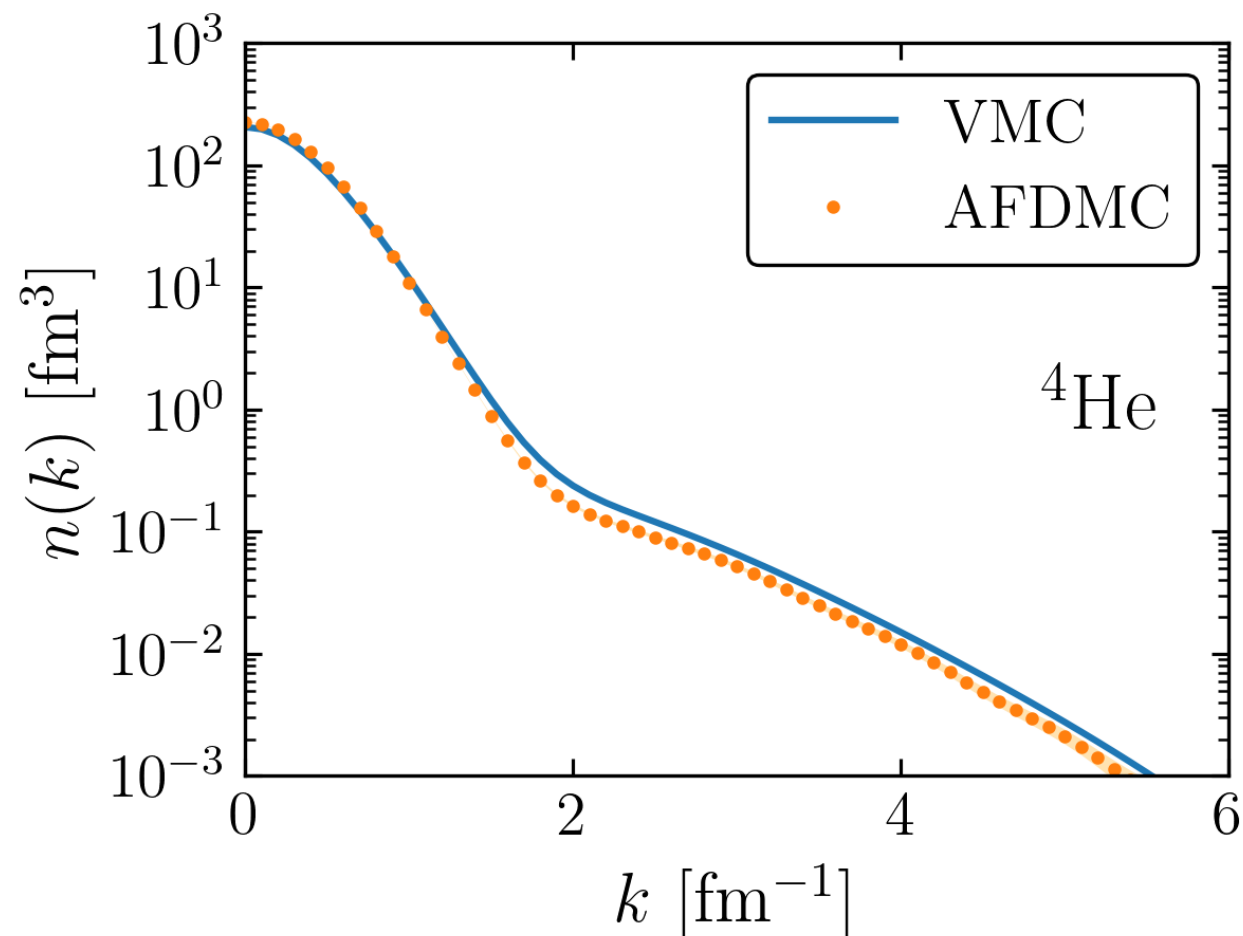
NR, A. Lovato, R. Wiringa, et al, in preparation

GFMC: many-body basis $\longrightarrow |S\rangle \equiv C_{\uparrow\uparrow\uparrow}|\uparrow\uparrow\uparrow\rangle + C_{\uparrow\uparrow\downarrow}|\uparrow\uparrow\downarrow\rangle + \dots + C_{\downarrow\downarrow\downarrow}|\downarrow\downarrow\downarrow\rangle$

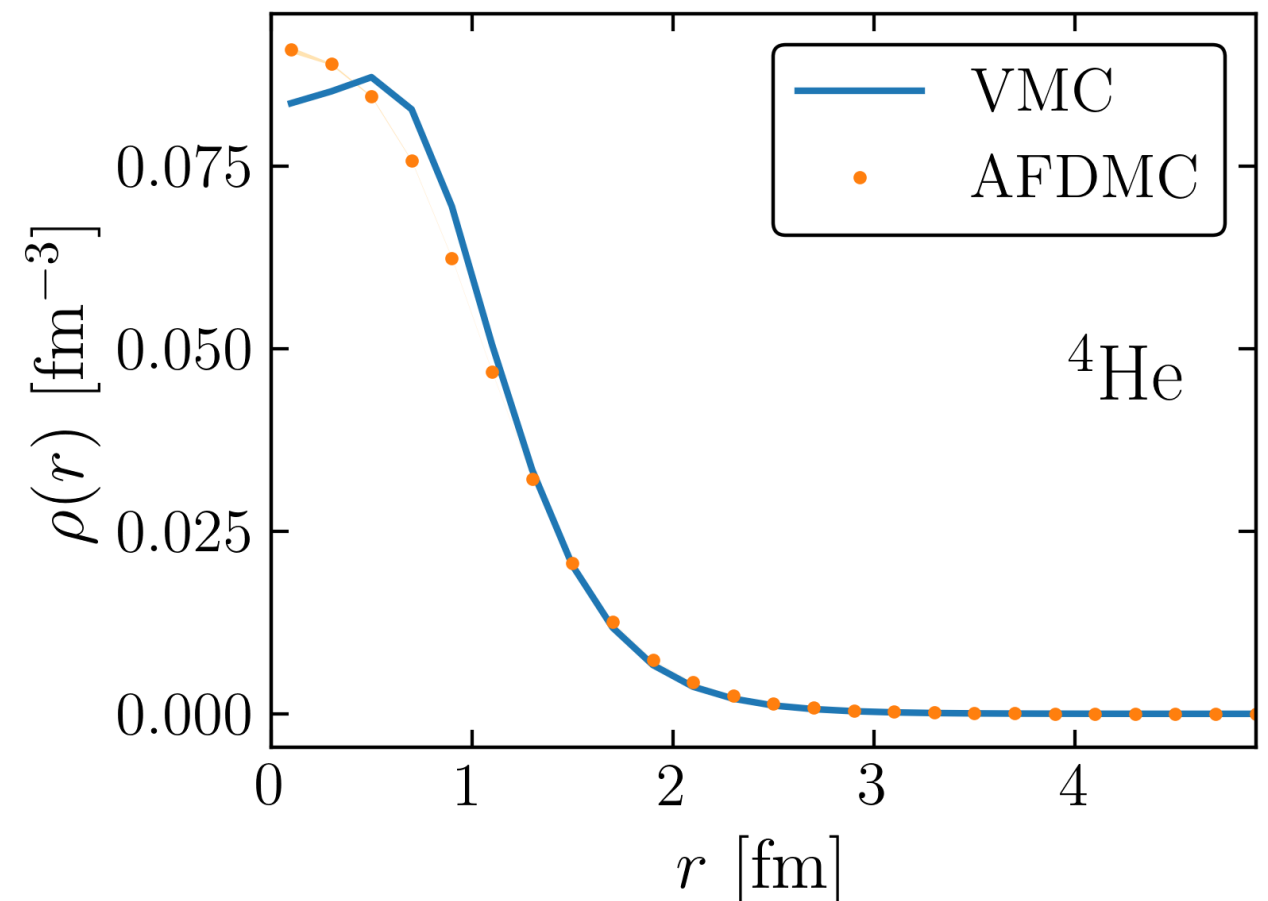
AFDMC: single-spinor basis $\longrightarrow |S\rangle \equiv (u_1|\uparrow\rangle_1 + d_1|\downarrow\rangle_1) \otimes \dots (u_A|\uparrow\rangle_A + d_A|\downarrow\rangle_A)$

This allows us to use QMC techniques to describe ^{16}O relevant for T2K and Hyper-K

AFDMC point nucleon density of ^4He compared with the VMC method



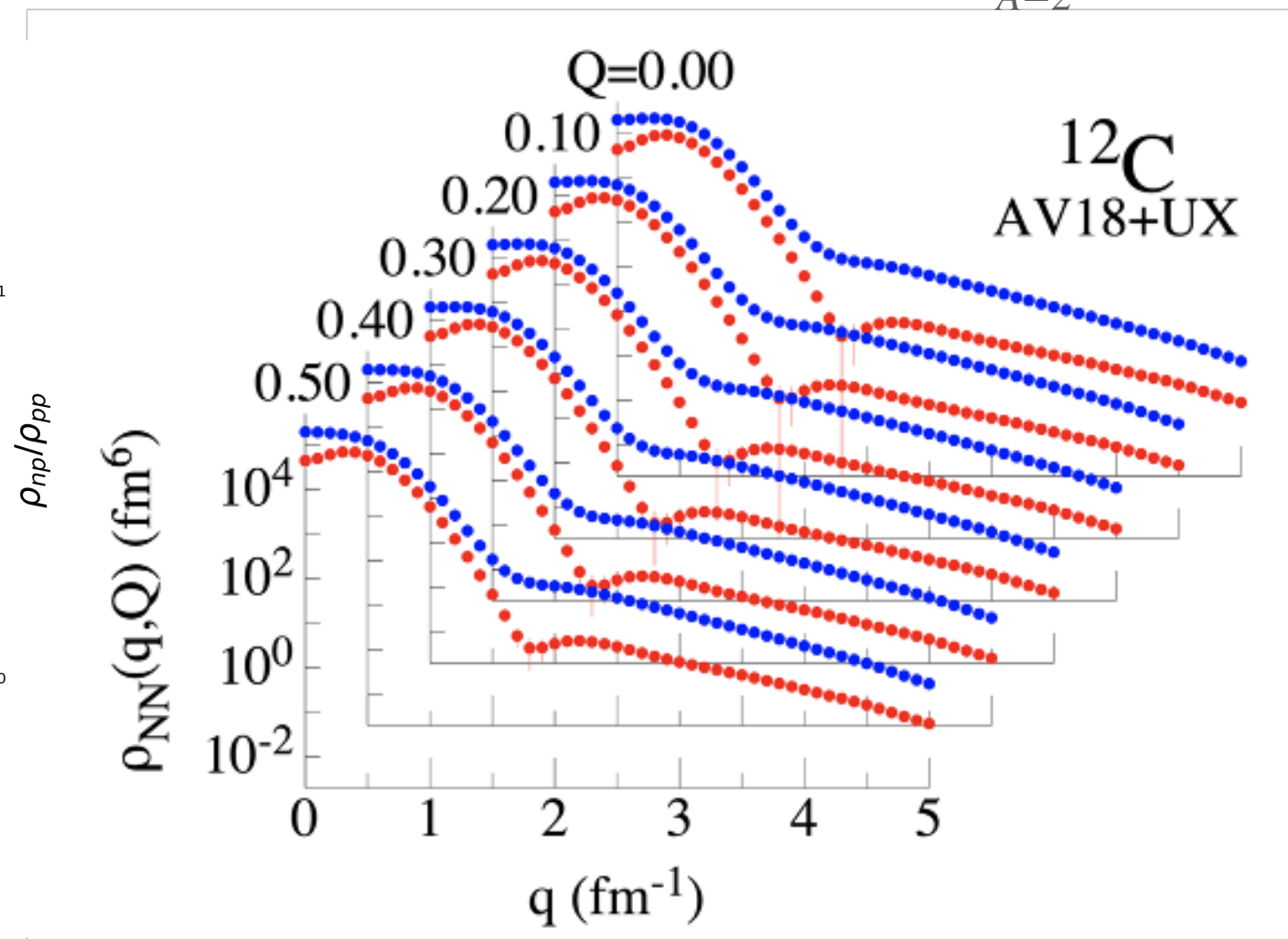
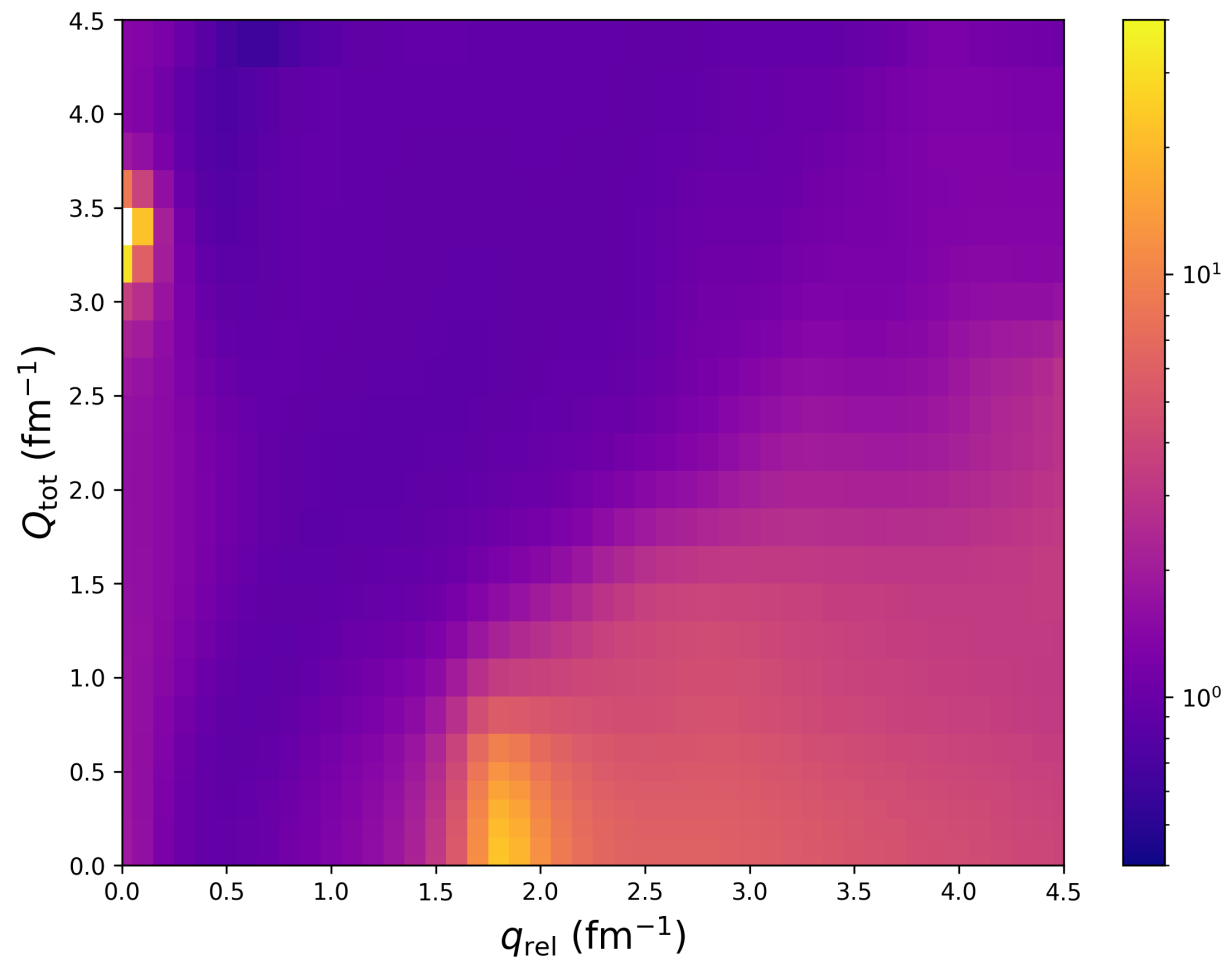
AFDMC momentum distribution of ^4He compared with the VMC method



Exclusive events with two-nucleon emission

NR, N. Steinberg, [2602.02231](#)

Two-body spectral function:
$$P_{ST}(k, k', \cos \theta_{kk'}, E) = \rho_{ST}(\mathbf{q}, \mathbf{Q}) \delta\left(E - B_0 + B_{A-2} - \frac{Q^2}{2m_{A-2}}\right)$$



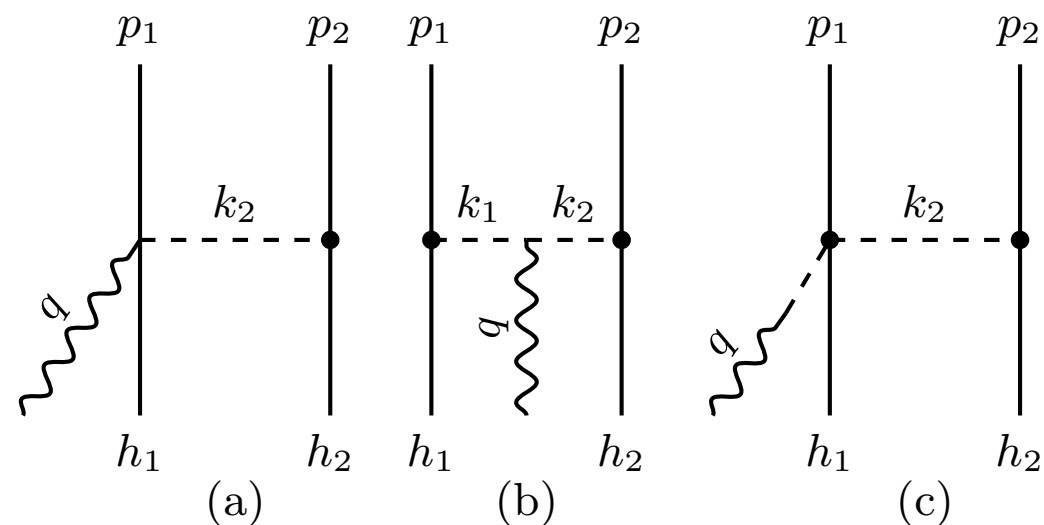
Wiringa, et al., Phys. Rev. C 89, 024305 (2014)

pp back-to-back pairs are in S states, have a knot at $q = 2 \text{ fm}^{-1}$

pn are in deuteron-like waves, where the D wave fills in the S-wave node

Exclusive events with two-nucleon emission

NR, N. Steinberg, [2602.02231](#)



- Diagrams contain Δ -resonance and background terms required by chiral symmetry
- For the Δ -propagator we removed the spurious 1/2 contribution

$$\tilde{G}_{\alpha\beta} = \frac{\tilde{P}_{\alpha\beta}}{p_{\Delta}^2 - M_{\Delta}^2 + i\Gamma M_{\Delta}}$$

we now replace

$$\tilde{P}_{\alpha\beta} = \frac{p_{\Delta}^2}{M_{\Delta}^2} \tilde{P}_{\mu\nu}^{\frac{3}{2}}$$

- We use updated couplings and consistent form factors

E. Hernandez, J. Nieves, and M. Valverde, Phys. Rev. D 76, 033005 (2007)

E. Hernandez and J. Nieves, Phys. Rev. D 95, 053007 (2017)

J. E. Sobczyk and J. Nieves, Phys. Rev. C 111, 025502 (2025)

Exclusive Meson Exchange Currents

NR, N. Steinberg, 2602.02231

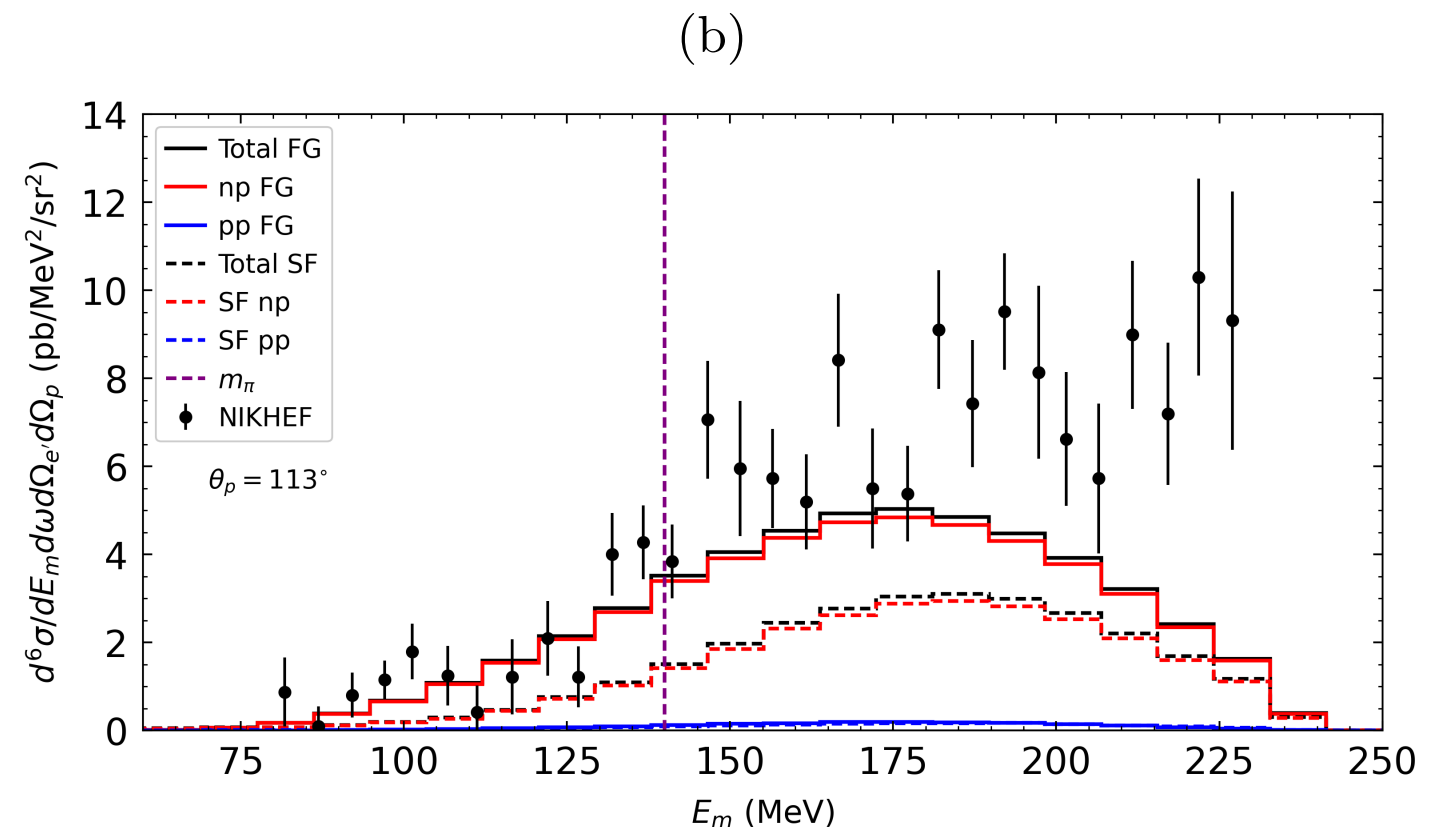
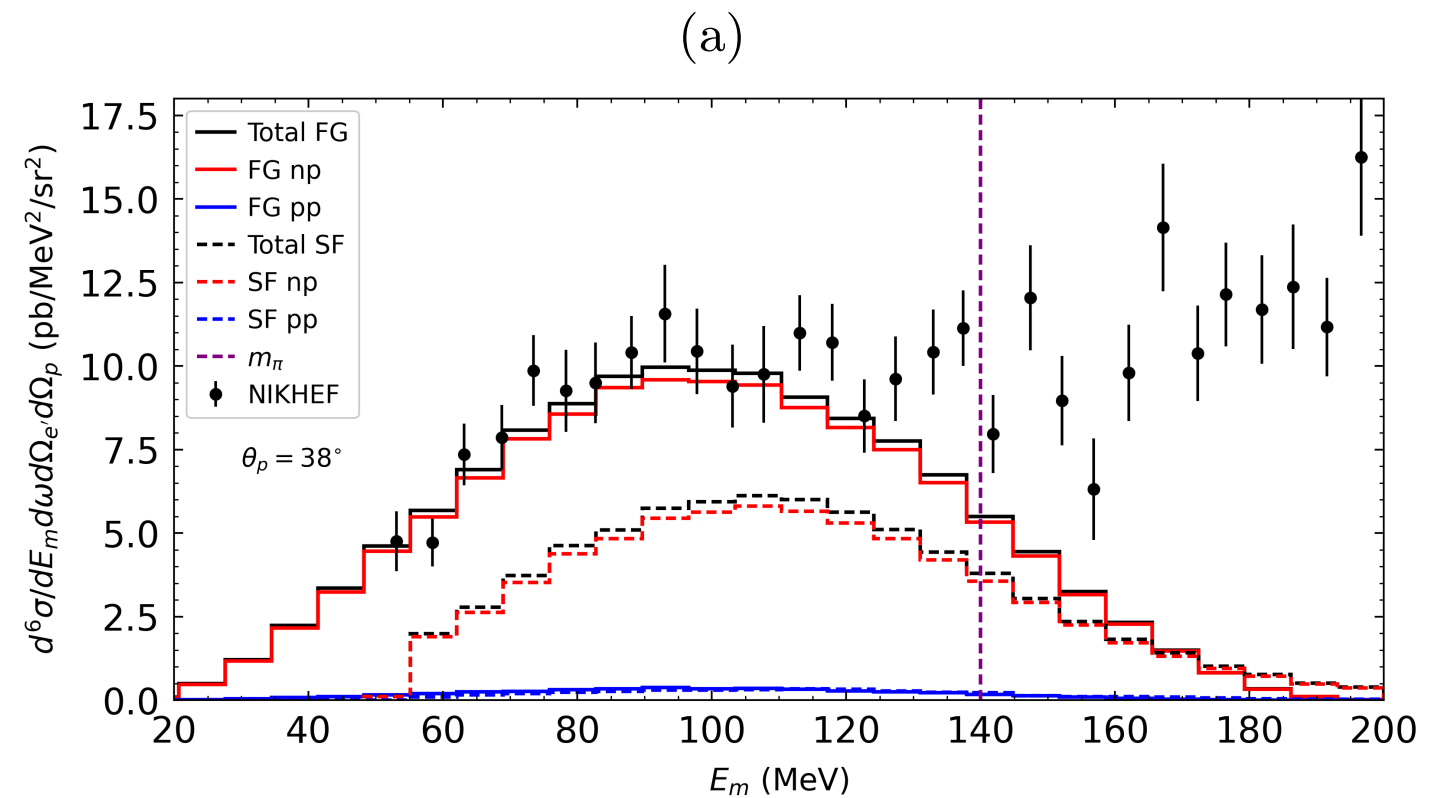
- Analysis for $^{12}\text{C}(e,e'p)$ scattering

Comparison with NIKHEF data for
 $E_e=478$ MeV,

$q=303$ MeV, $\omega=263$ MeV, $\theta_p=38^\circ$

(a), $\theta_p=113^\circ$ (b)

DISCLAIMER: Experimental data include contributions from additional reaction mechanisms that are not incorporated in the theory

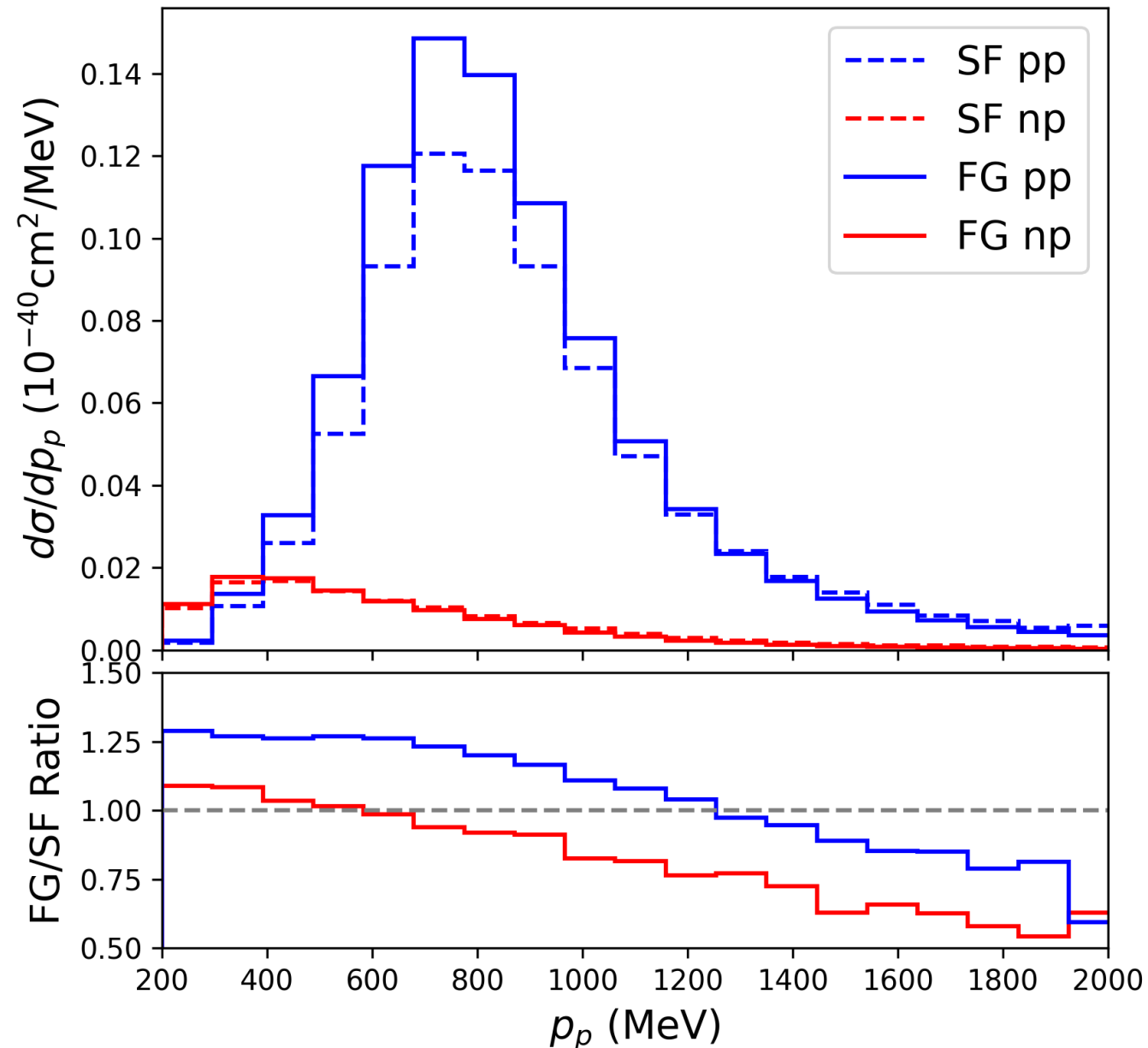


Exclusive Meson Exchange Currents

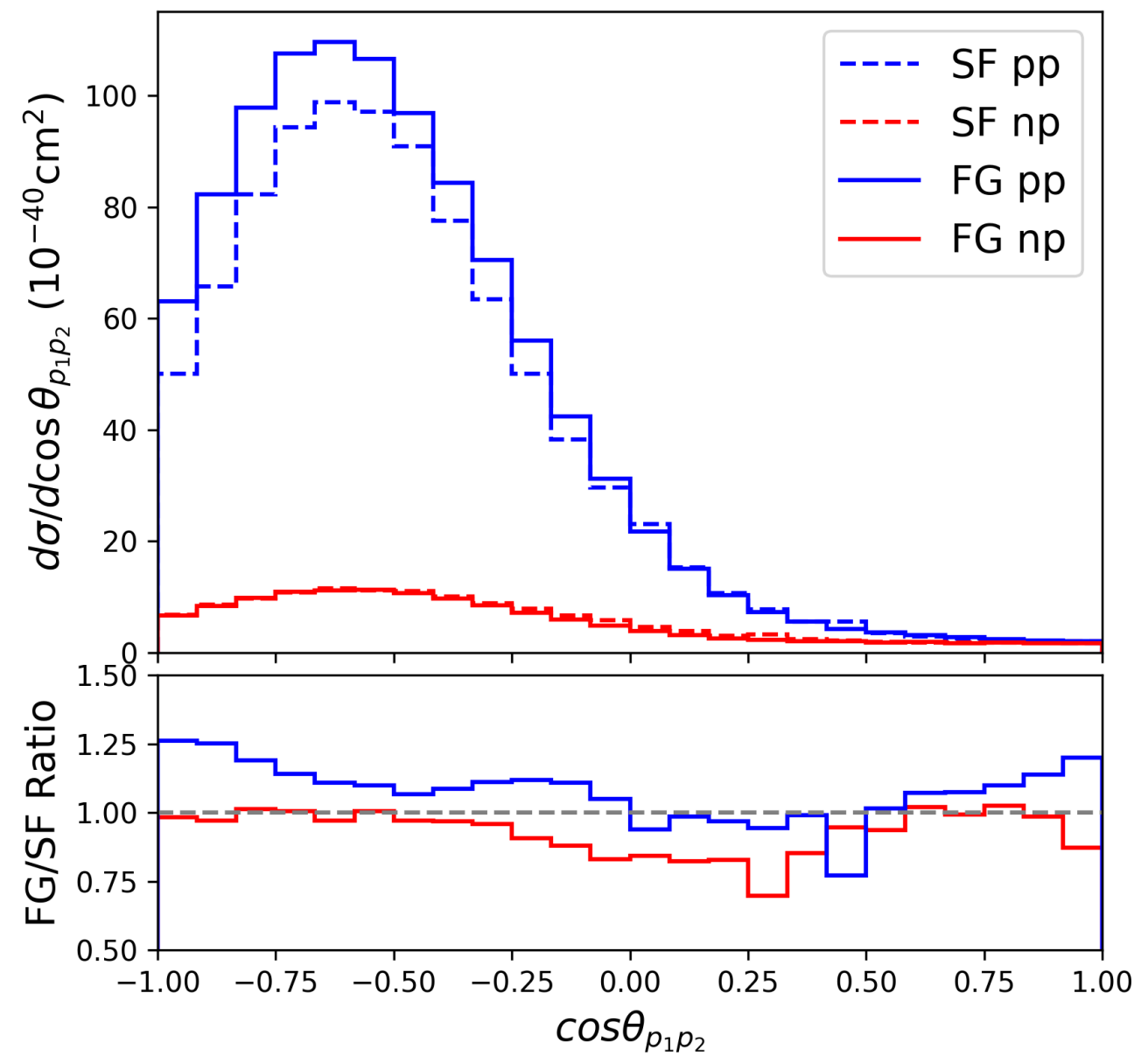
NR, N. Steinberg, [2602.02231](#)

- T2K flux-folded cross section

- Leading proton momentum



- Angle between outgoing nucleons



Inverse Problem: LIT - Synthetic case

We consider the Lorentz Kernel given by

$$L(\omega_0, \Gamma, \sigma) = \int d\omega \frac{1}{\pi} \frac{\Gamma R(\omega, \mathbf{q})}{\Gamma^2 + (\omega - \omega_0)^2}$$

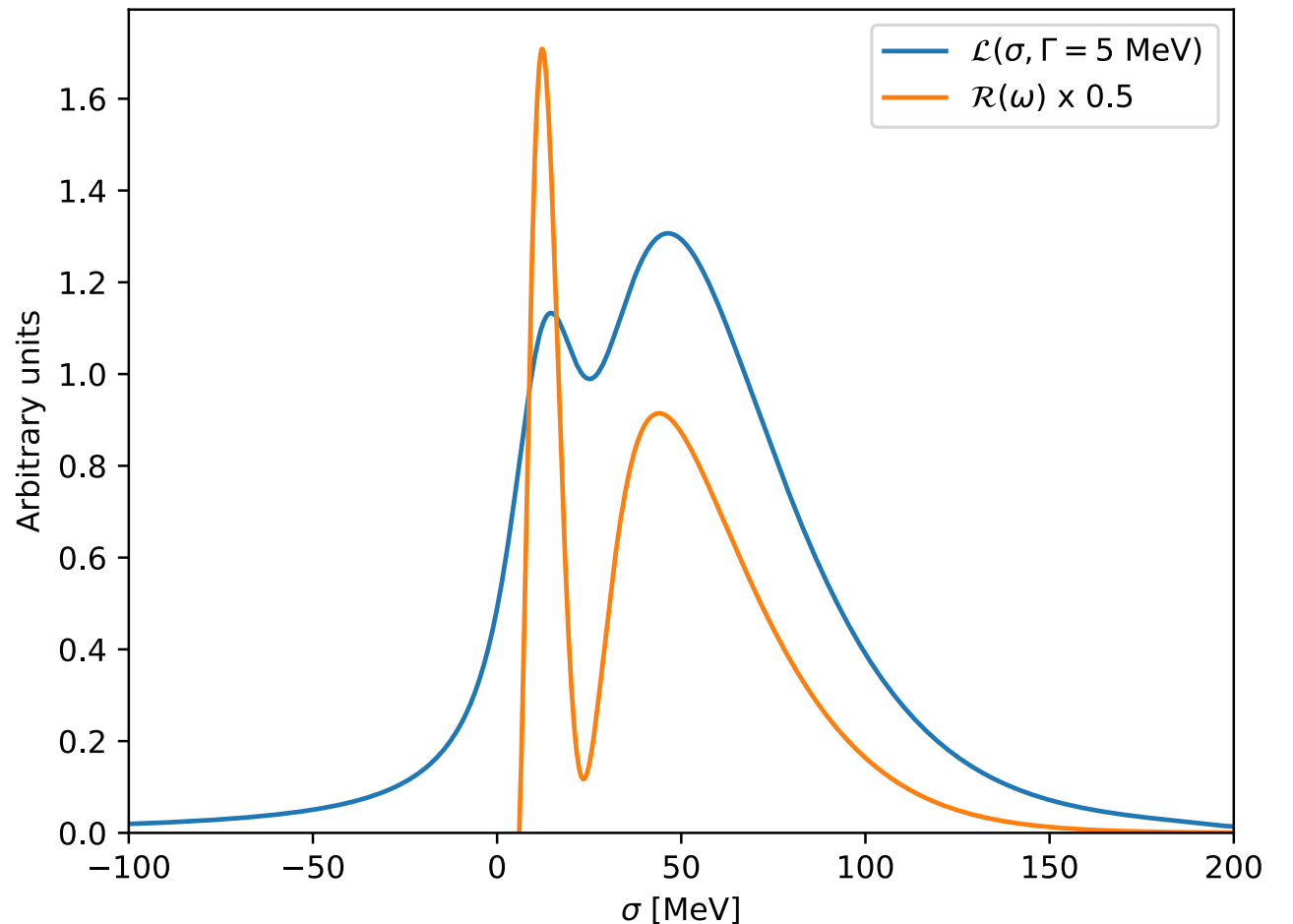
Ansatz used to start the inversion:

$$\widetilde{R}(\omega_i) = (1 + c_i)^2 m(\omega_i) \quad \text{with } \{\omega_i\}_{i=1}^{N_\omega}$$

Where c_i have the same cardinality of ω_i .

We do not impose any information on the threshold.

This multiplicative form guarantees $\widetilde{R}(\omega_i) \geq 0$ whenever $m(\omega_i) \geq 0$, without imposing additional constraints during the optimization.



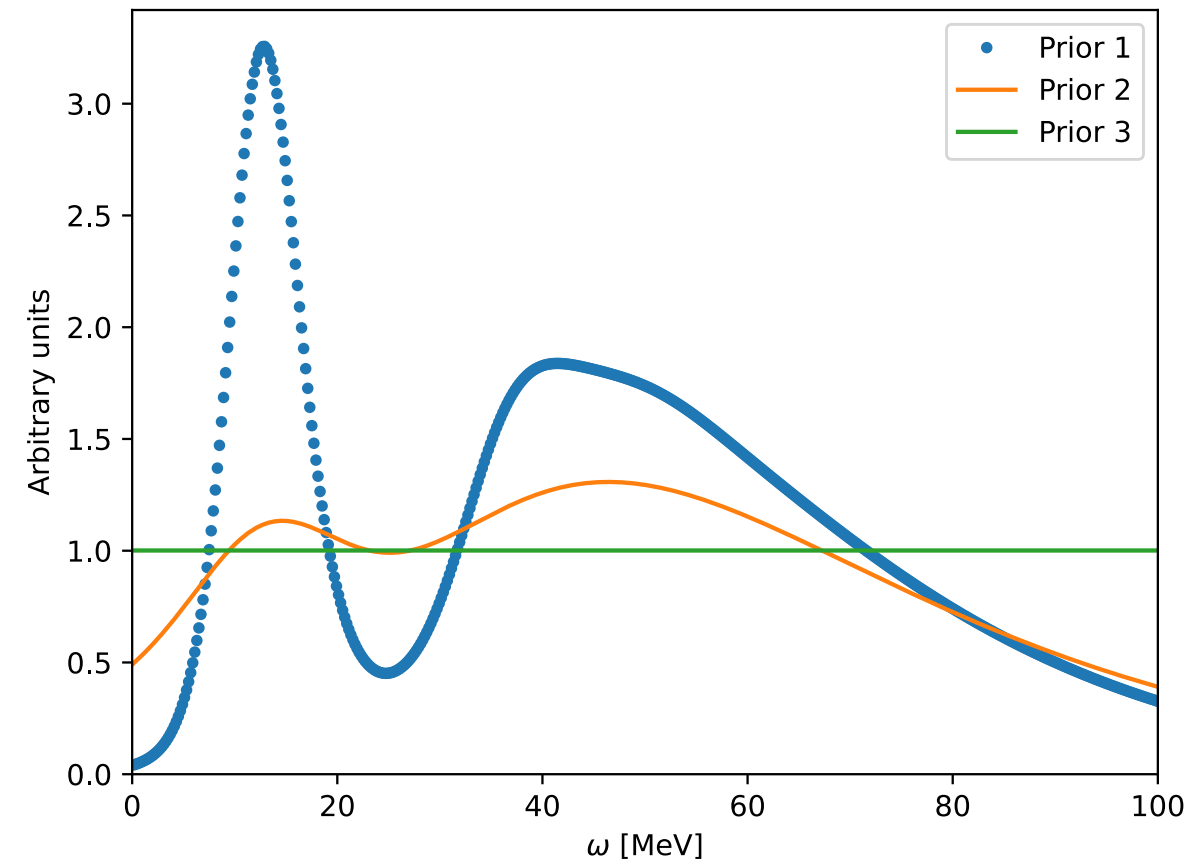
Inverse Problem: LIT - Synthetic case

- Different models used

Hence, the prior is conditional on both the model and α

$$P(R|m, \alpha) = \frac{e^{\alpha S}}{Z_S},$$

The α - dependent normalization constant Z_S can be estimated by approximating the exponential with a Gaussian centered at $R_i = m_i$

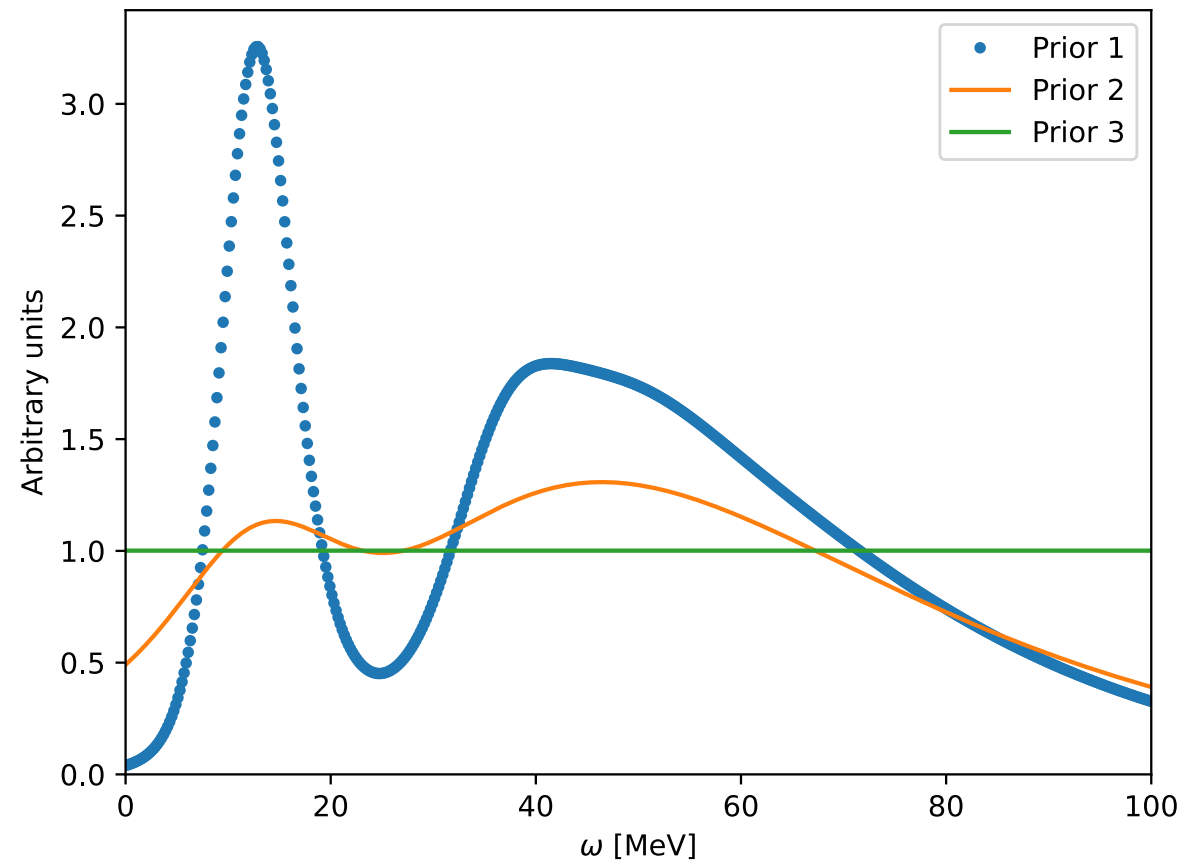


$$Z_S = \int \prod_{i=1}^{N_\omega} \frac{dR_i}{\sqrt{R_i}} \exp \left\{ \alpha \left[R_i - m_i - R_i \log \left(\frac{R_i}{m_i} \right) \right] \Delta\omega \right\} \simeq \left(\frac{2\pi}{\alpha} \right)^{N_\omega/2}.$$

Thus the posterior is given by

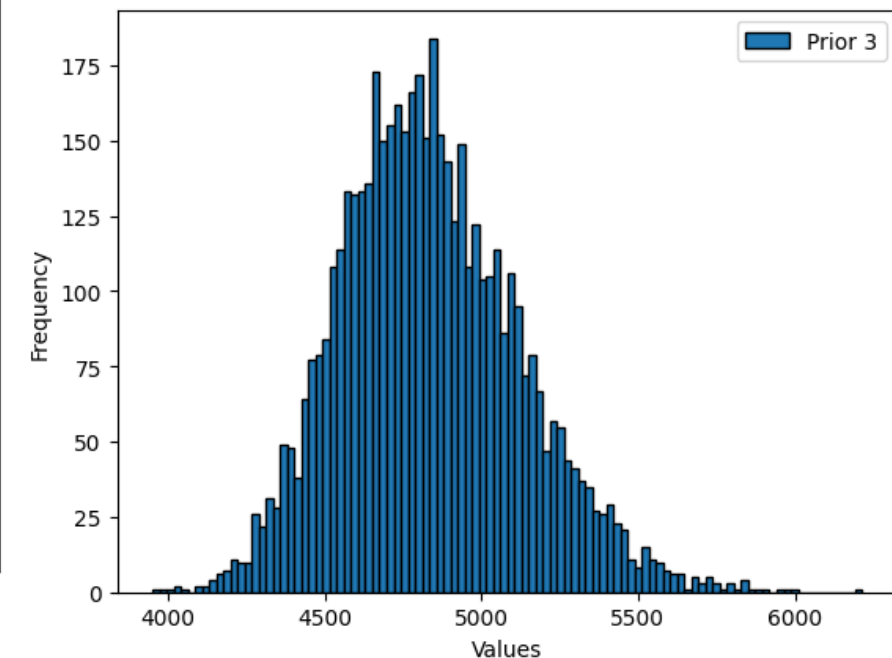
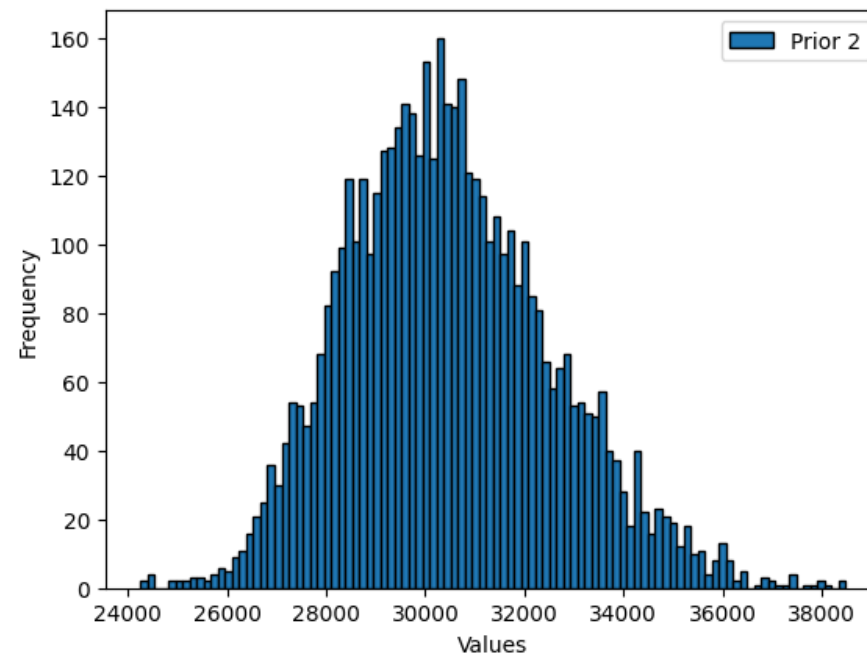
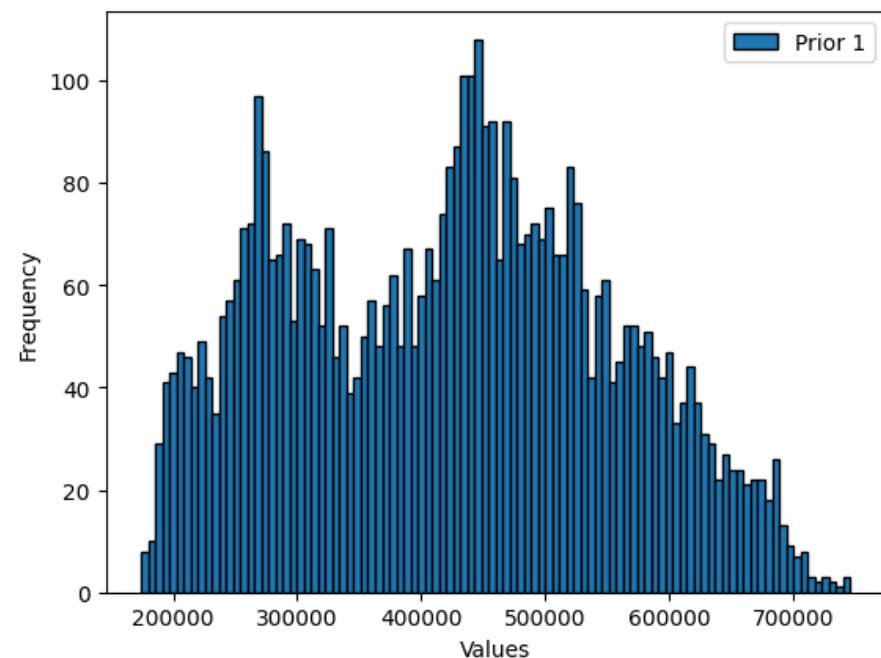
$$P(R|\mathcal{L}, m, \alpha) = \frac{e^{\alpha S - \chi^2/2}}{Z_S Z_L}$$

Inverse Problem: LIT - Synthetic case

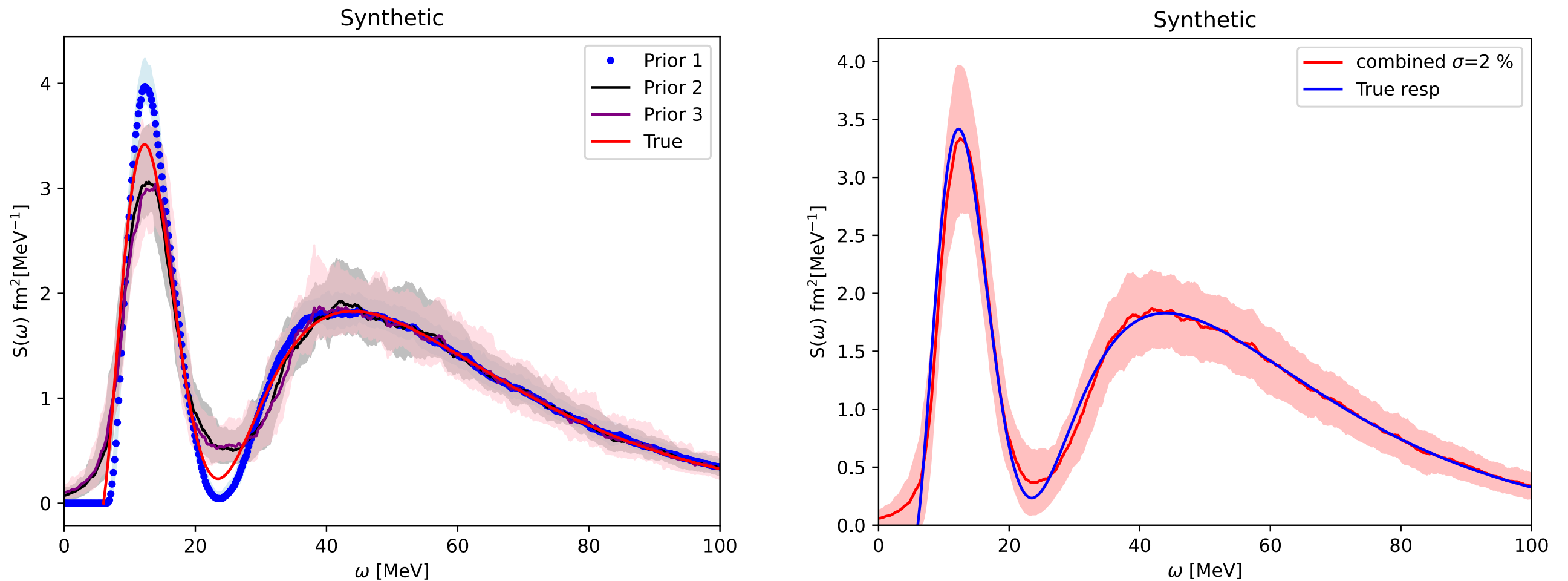


Large experimental error $\rightarrow$ the **likelihood** becomes **less informative** and the **posterior** shifts toward values of α for which the **entropy term dominates**.

The reconstructed response is progressively driven toward the default model (prior)



Inverse Problem: Lorentz Integral Transform



On the left, we analyze the dependence on the different priors chosen

On the right, we combine the three reconstructions by treating them as an equally weighted ensemble over priors

The final **error envelope** is therefore wide when either a given **inversion** is **poorly constrained** or the **result is sensitive to the choice of prior**.

Inverse Problem: LIT - CC dipole response

We consider a dipole excitation operator: $J = \sum_{i=1}^A P_i (z_i - Z_{cm})$

Preliminary results using Bayesian techniques

Inversion algorithm generally starts from:

$$R(\omega) = \sum_{n=1}^N c_n \chi_n(\omega', \alpha_1, \alpha_2, \beta)$$

$$\omega' = \omega - \omega_{th}$$

Polynomials defined as

$$\chi_1(\omega, \alpha_1, \alpha_2, \beta) = \omega^{\alpha_1} \exp(-\alpha_2 \omega),$$

$$\chi_{n \geq 2}(\omega, \alpha_1, \alpha_2, \beta) = \omega^{\alpha_1} \exp\left(-\frac{\alpha_2 \omega}{\beta n}\right)$$

V D Efros, et al., J. Phys. G: Nucl. Part. Phys. 34 R459

