NSAT Section Meeting
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# COMPUTING NEUTRINO-NUCLEUS QUASIELASTIC CROSS SECTIONS FOR PRECISION NEUTRINO EXPERIMENTS

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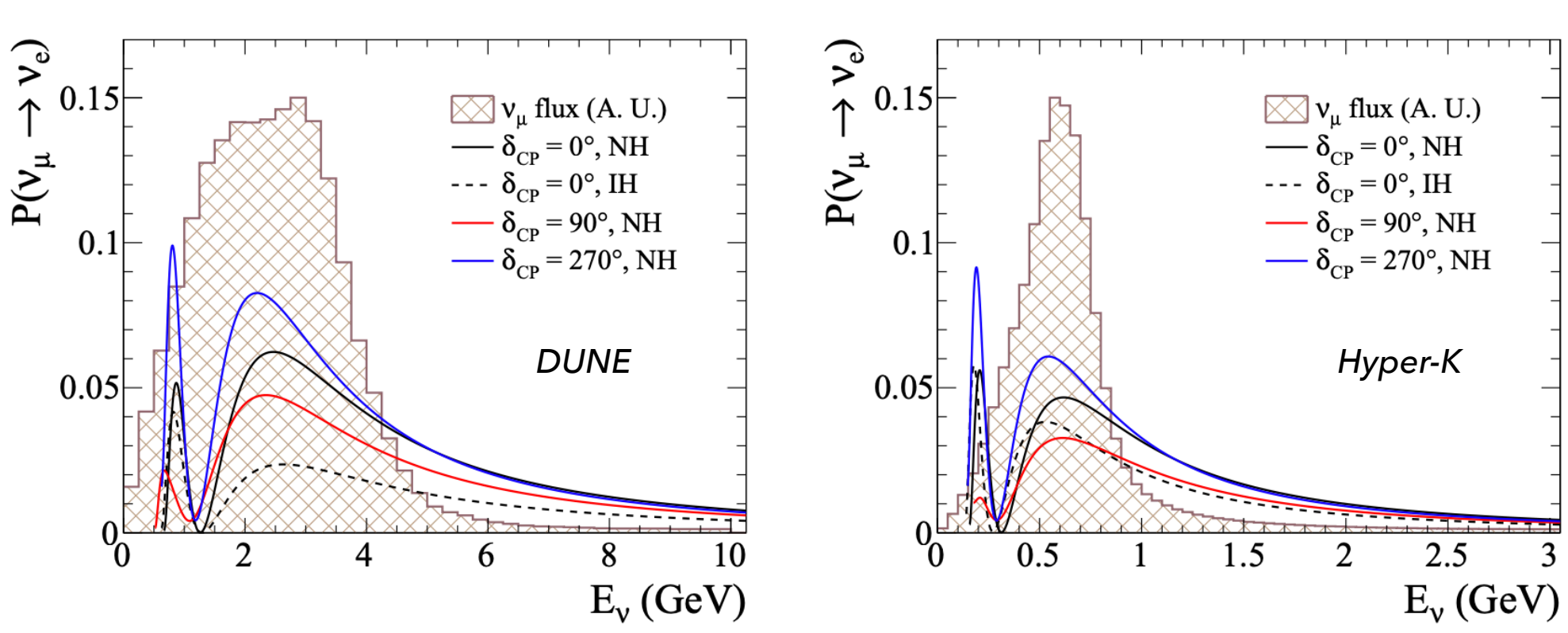
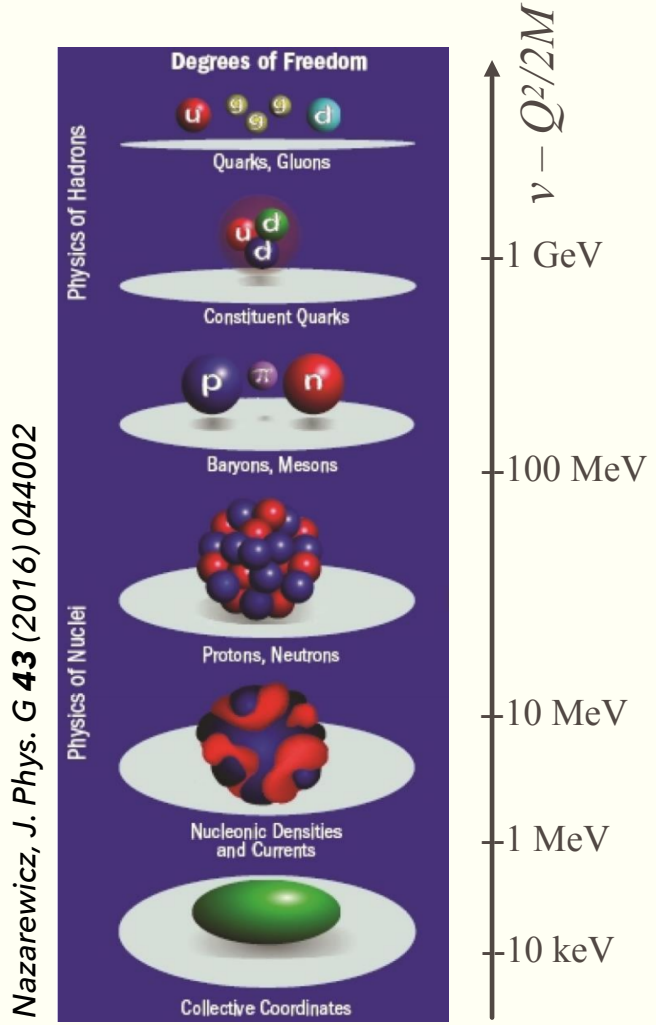
# Simulated neutrino oscillation probabilities

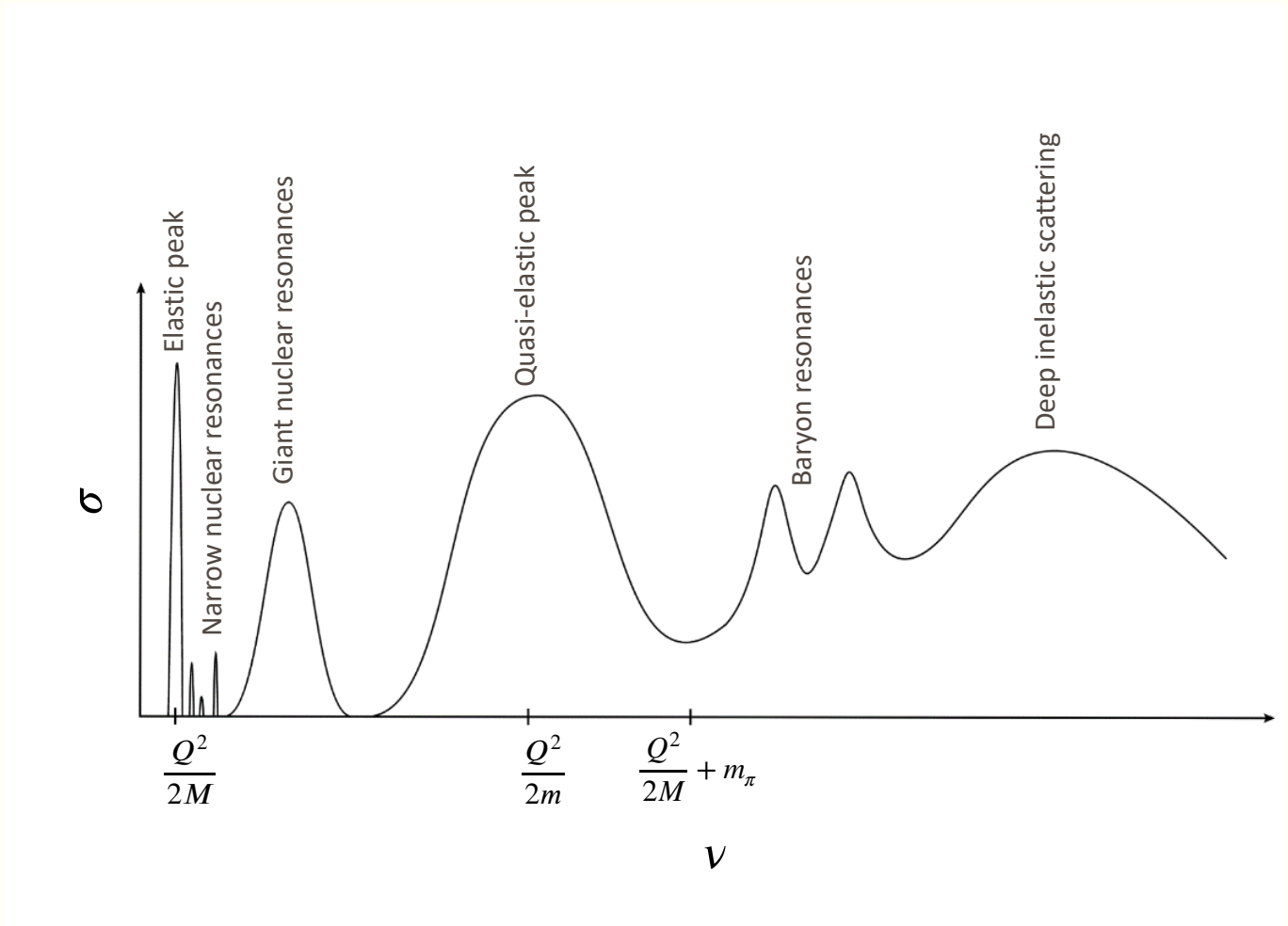



*Diwan et al., Ann. Rev. Nucl. Part. Sci.* ***66*** *(2016) 47*

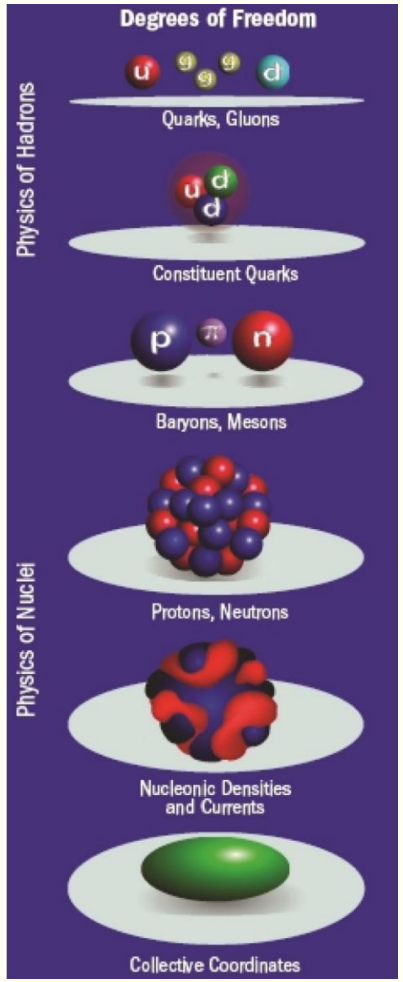
# Nucleus at different resolutions



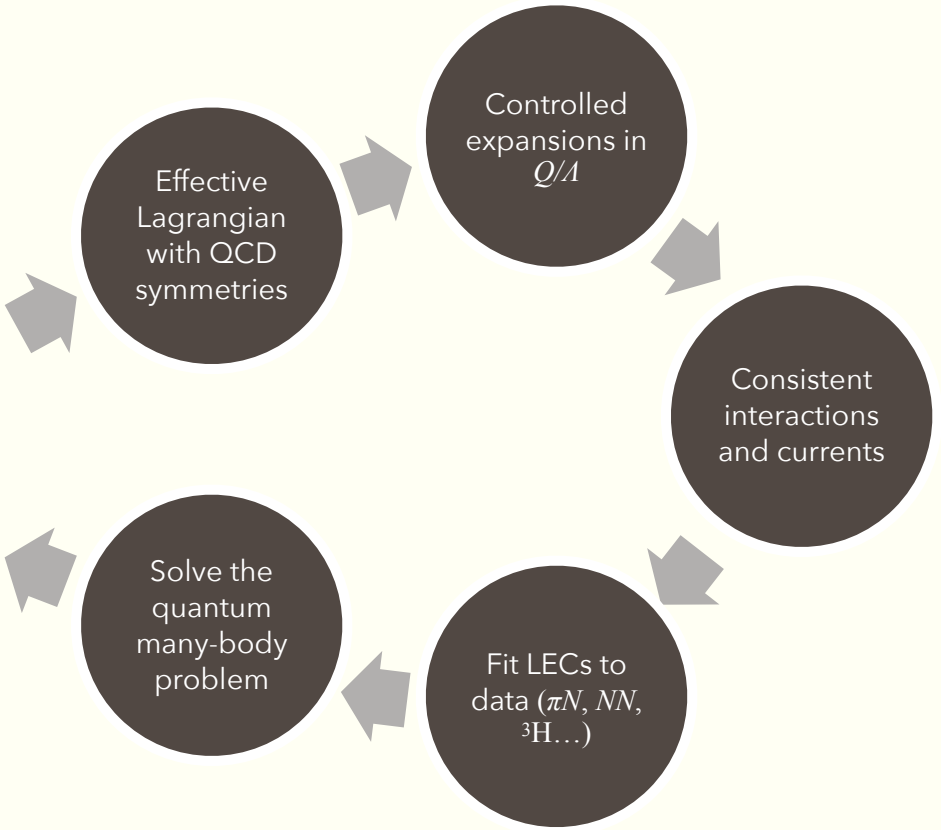

Nazarewicz, J. Phys. G **43** (2016) 044002

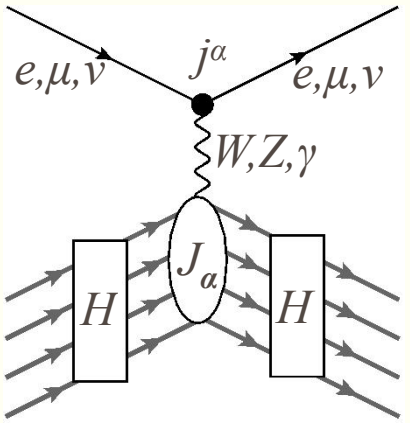


# Chiral effective field theory ($\chi$EFT)




*Nazarewicz, J. Phys. G* **43** *(2016) 044002*



# Nuclear electroweak response functions

- Vector part of the weak current, $J_\alpha \equiv V_\alpha + A_\alpha$ , tested on electron-scattering data

$$\left.\frac{d\sigma}{d\Omega\, dq}\right|_{\nu/\bar{\nu}} = v_L R_L + v_{0z} R_{0z} + v_{zz} R_{zz} + v_T R_T \pm v_{T'} R_{T'}$$

$$\left.\frac{d\sigma}{d\Omega\, dq}\right|_{e^-} = v_L R_L + v_T R_T$$

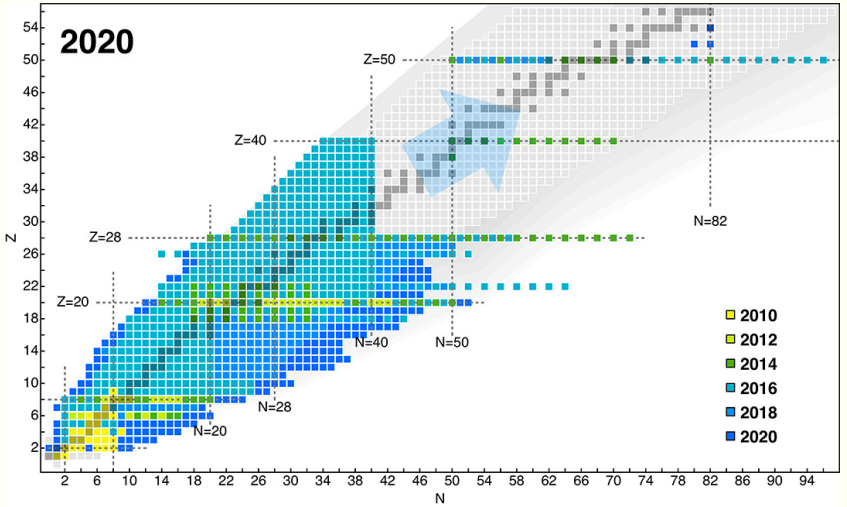
- Response functions contain all information about the nuclear system and can also be compared against other observables (photodissociation, muon capture …)

$$R_{\alpha\beta}(\nu, q) = \sum_f \langle \Psi | J_\alpha^\dagger | \Psi_f \rangle \langle \Psi_f | J_\beta | \Psi \rangle \, \delta(E_f + q^2/2M - E - \nu)$$

# Coupled-cluster theory (and Co.)


## *"Ab initio"* methods

Solve the $A$-body Schrödinger equation with *only controlled approximations*.

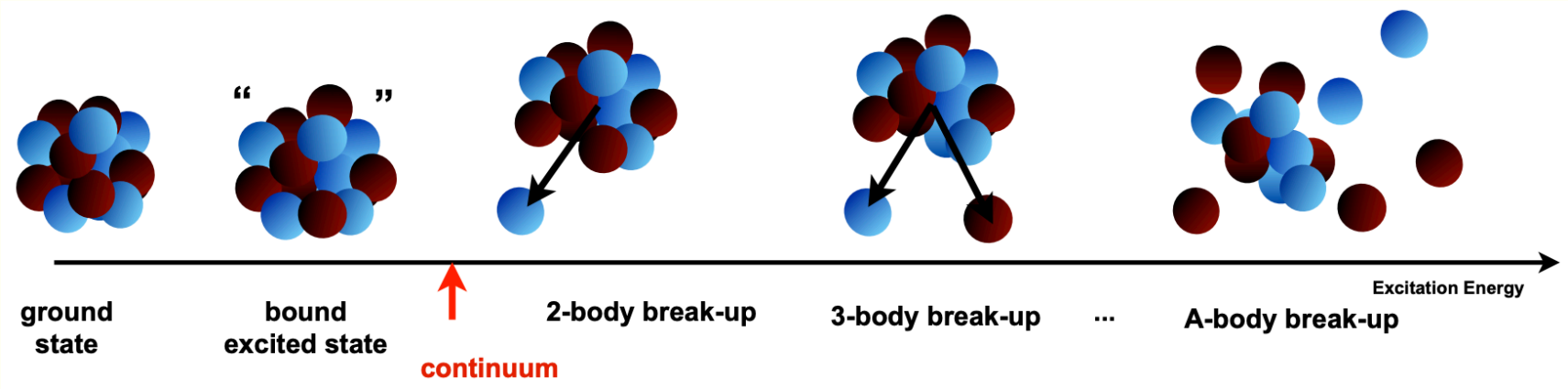



*Hergert, Front. Phys.* ***8*** *(2020) 379*

# Response functions from many-body computations

- Recall

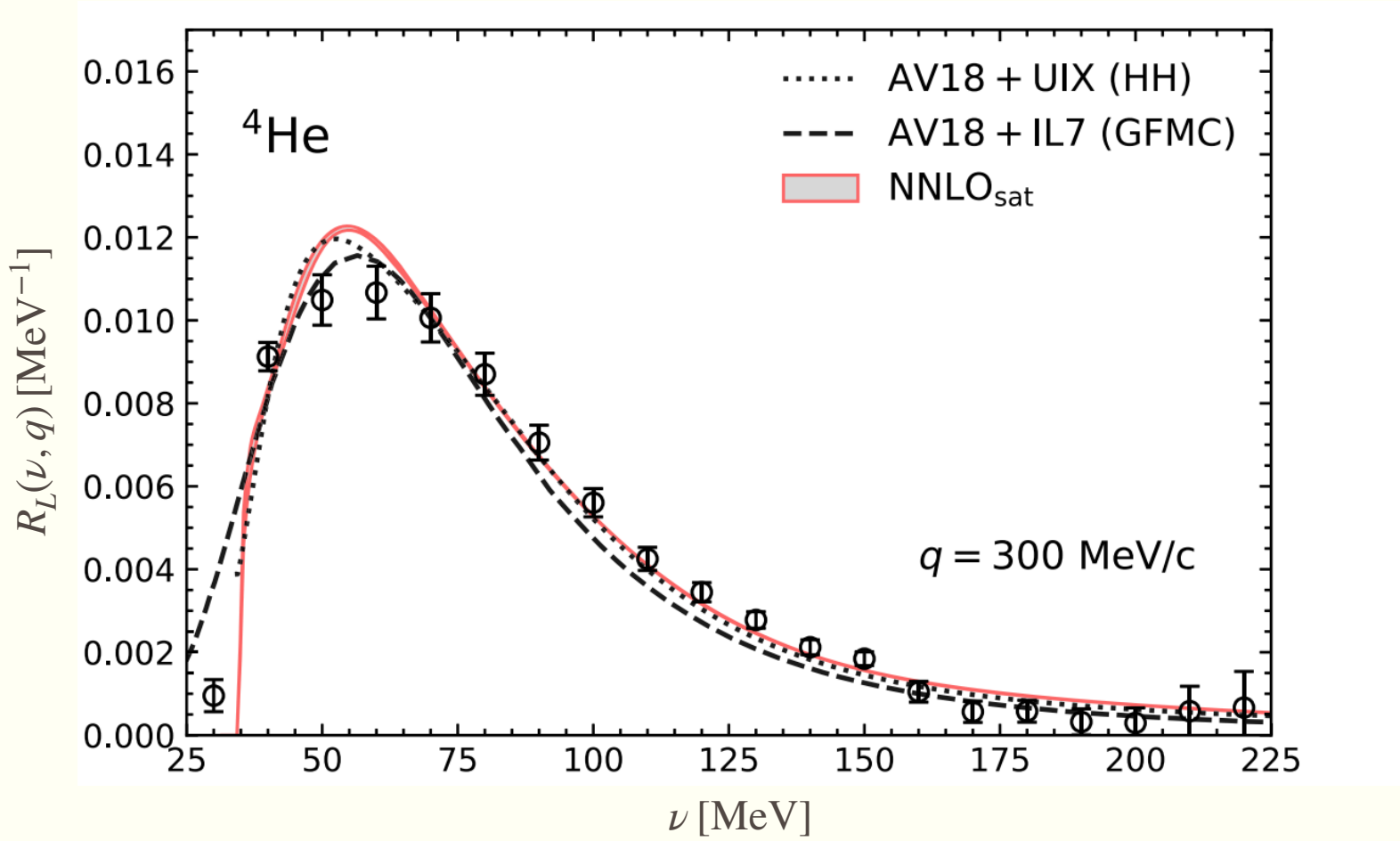
$$R_L(\nu, q) = \sum_f \langle \Psi | \rho^\dagger(q) | \Psi_f \rangle \langle \Psi_f | \rho(q) | \Psi \rangle \, \delta(E_f + q^2/2M - E - \nu)$$




- Integrate over energy (after folding with a preferred kernel), use completeness to relation to avoid having to explicitly calculate final states, and then “invert”.

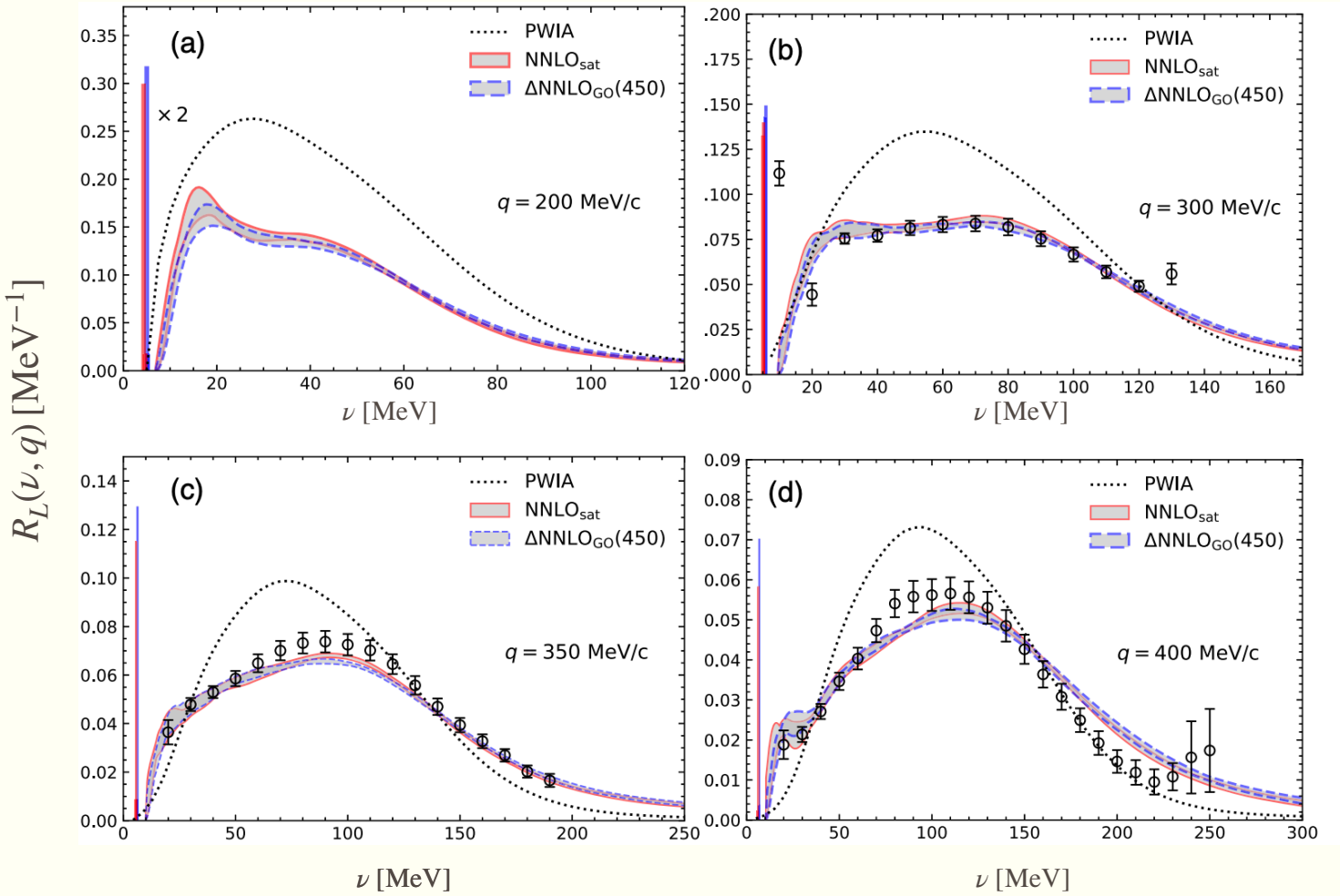
# Longitudinal response function: $^4$He

*J E Sobczyk, BA, S Bacca and G Hagen, Phys. Rev. Lett.* ***127*** *(2021) 072501*



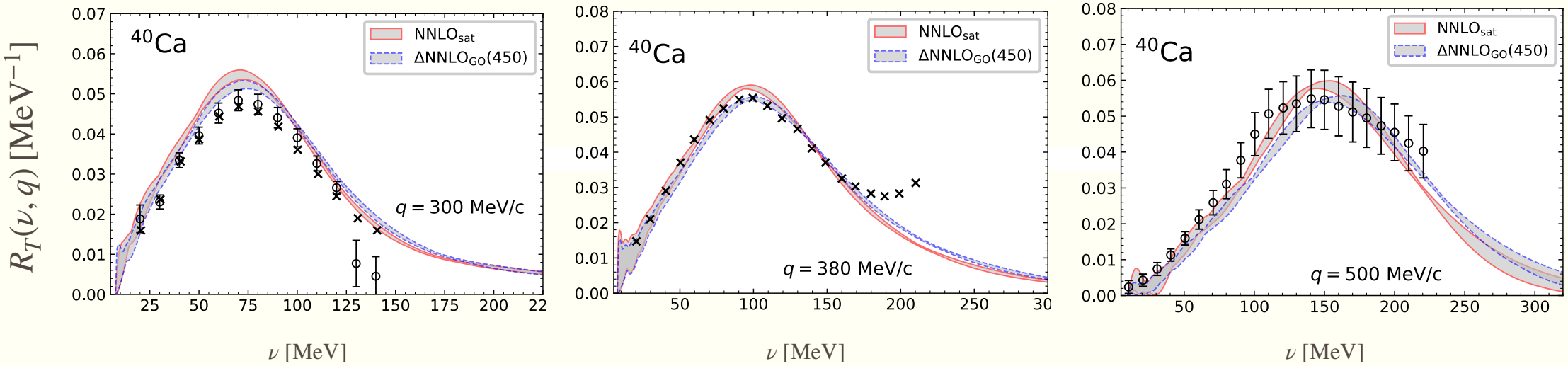
# Longitudinal response functions: $^{40}$Ca

*J E Sobczyk, BA, S Bacca and G Hagen, Phys. Rev. Lett.* ***127*** *(2021) 072501*



# Transverse response functions: $^{40}$Ca

*BA, J E Sobczyk, S Bacca and G Hagen, In Preparation*



# Directions

- Theory: Novel ideas for solution of the quantum many-body problem, inversion, “more effective” treatment of interactions and currents
- HPC: First ab initio many-body computations of quasielastic electron and neutrino cross sections on $^{16}O$, $^{40}Ar$…
- Experiments: addressing the needs of other neutrino experiments (@ ORNL?)
- Machine Learning: fast and accurate emulators, model uncertainties, Bayesian Model Mixing with other theoretical approaches for intermediate kinematic regimes…