Neural Network for low-energy nuclear structure

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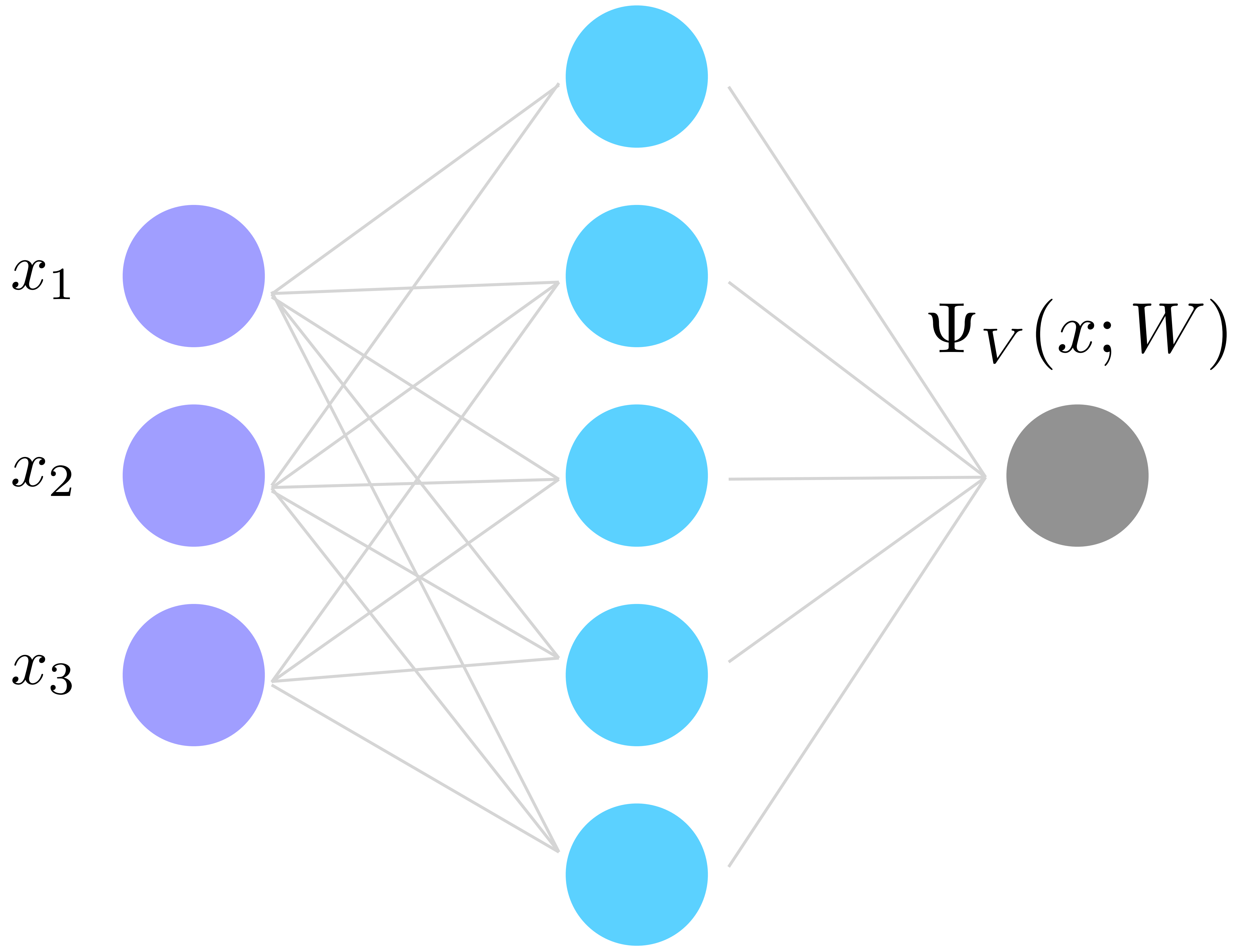
Neural-Network Quantum States



The energy is the loss function

$$E = \min_W \frac{\langle \Psi_V(W) | H | \Psi_V(W) \rangle}{\langle \Psi_V(W) | \Psi_V(W) \rangle}$$

Variational Principle

$x_i =$ position, spin, isospin

$W =$ weights of the network

Image courtesy of A. Lovato

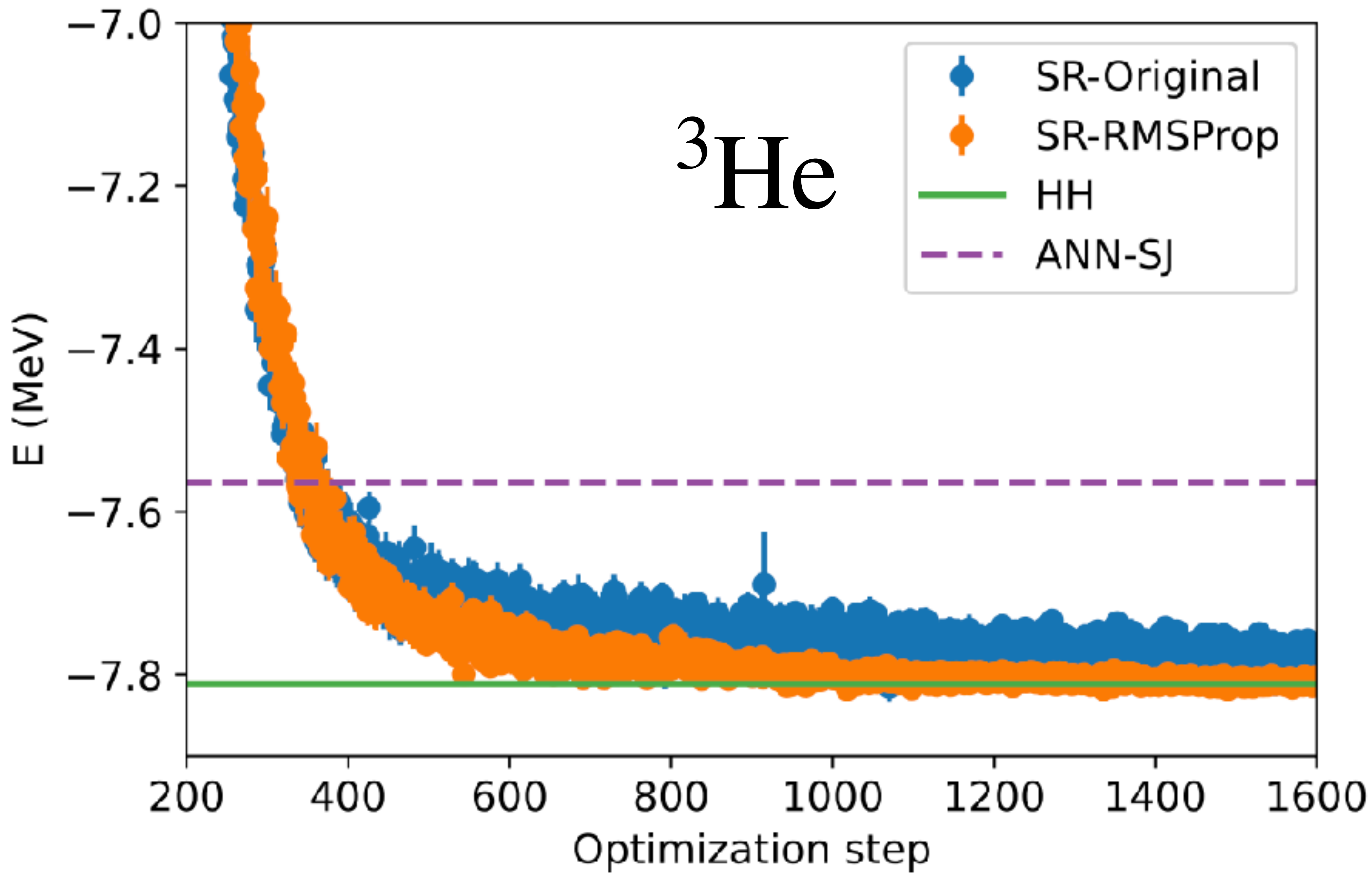
Optimization of the wave function

Monte Carlo Sampling

$$E(W) = \frac{\langle \Psi_V(W) | H | \Psi_V(W) \rangle}{\langle \Psi_V(W) | \Psi_V(W) \rangle}$$

Back propagation based on
Stochastic Reconfiguration Method

$$W_{new} = W_{old} + \delta W(\partial_W \Psi, \partial_W^2 \Psi, E(W))$$



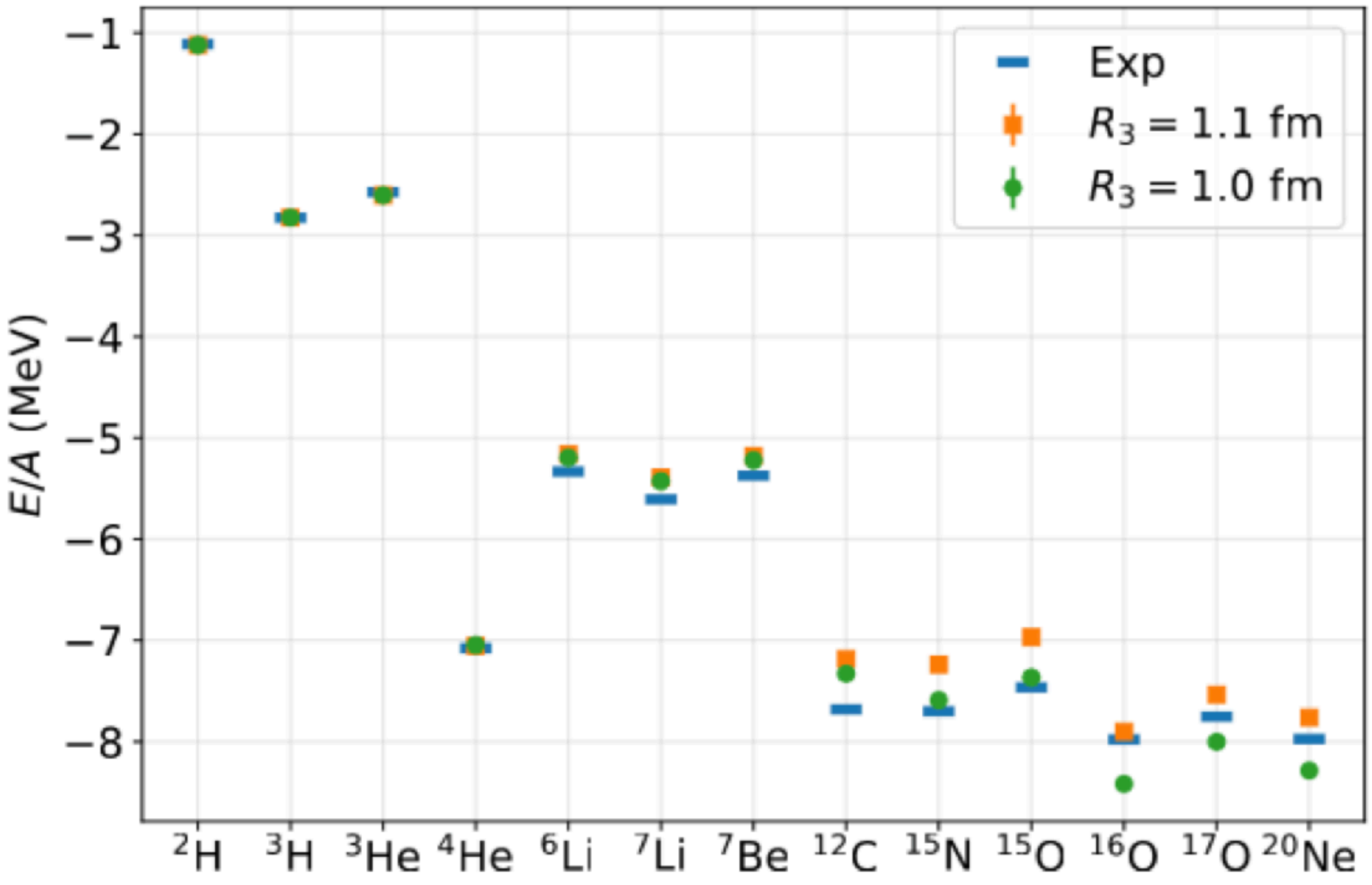
A. Lovato, et al., Phys. Rev. Res. **4**, 043178 (2022)

Why Neural Network Quantum-States for many-body?

Some on the computational advantages

- Variational approach (no sign problem)
- Polynomial scaling with the dimension of the problem ($\propto A^5$)
- **Code based on JAX (Python library for machine learning)**
- Exploit GPU based parallelization (single node until few months ago)

Binding energies of selected nuclei



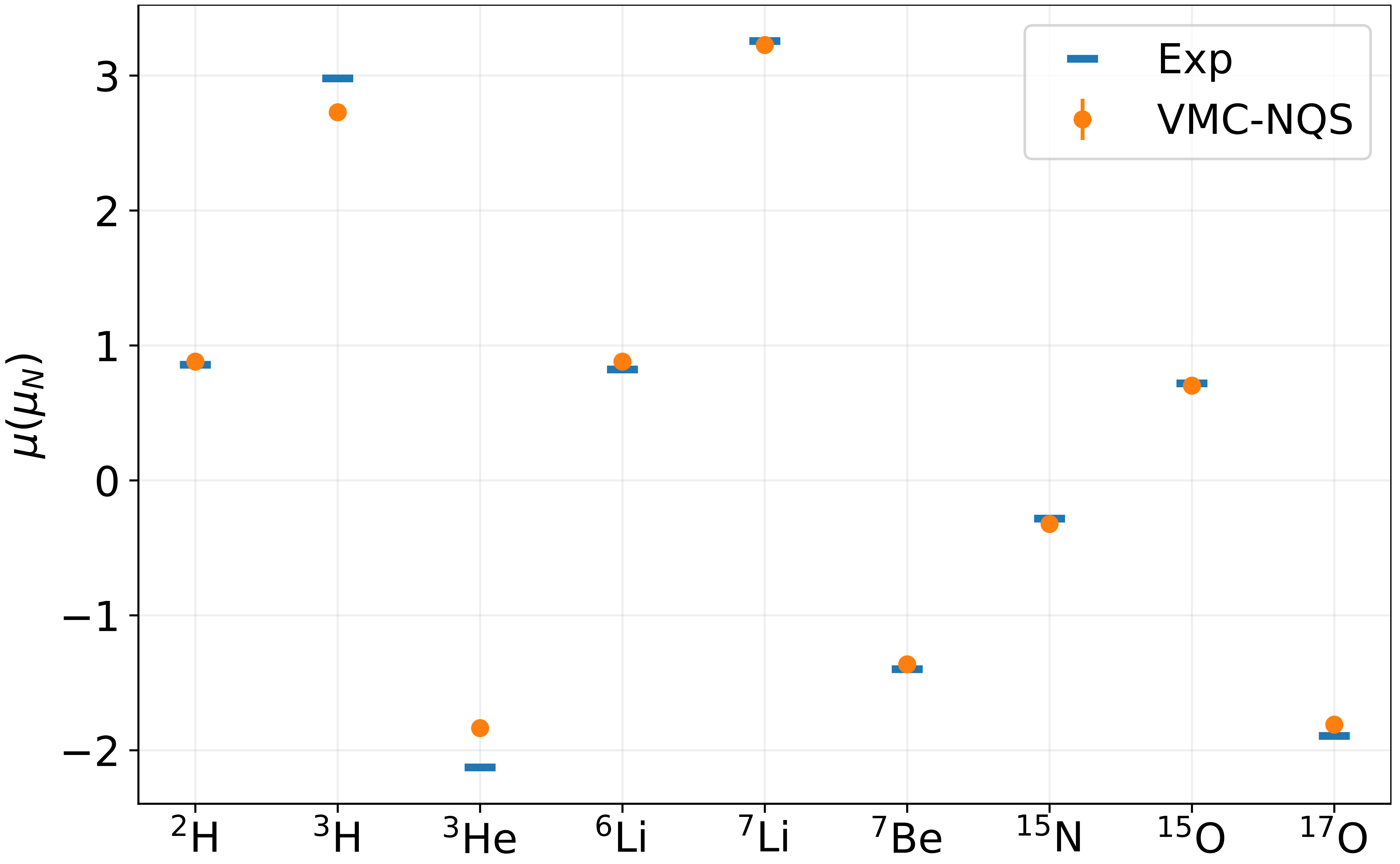
- **Very basic potential model (LO pionless EFT)**
- **Good agreement with the experimental values (<7%)**

No pretraining of the NQS on Hartree-Fock wave function!!

A.G., B. Fore, A. Lovato, and A. Tropiano, arXiv:2308.16266 (2023)

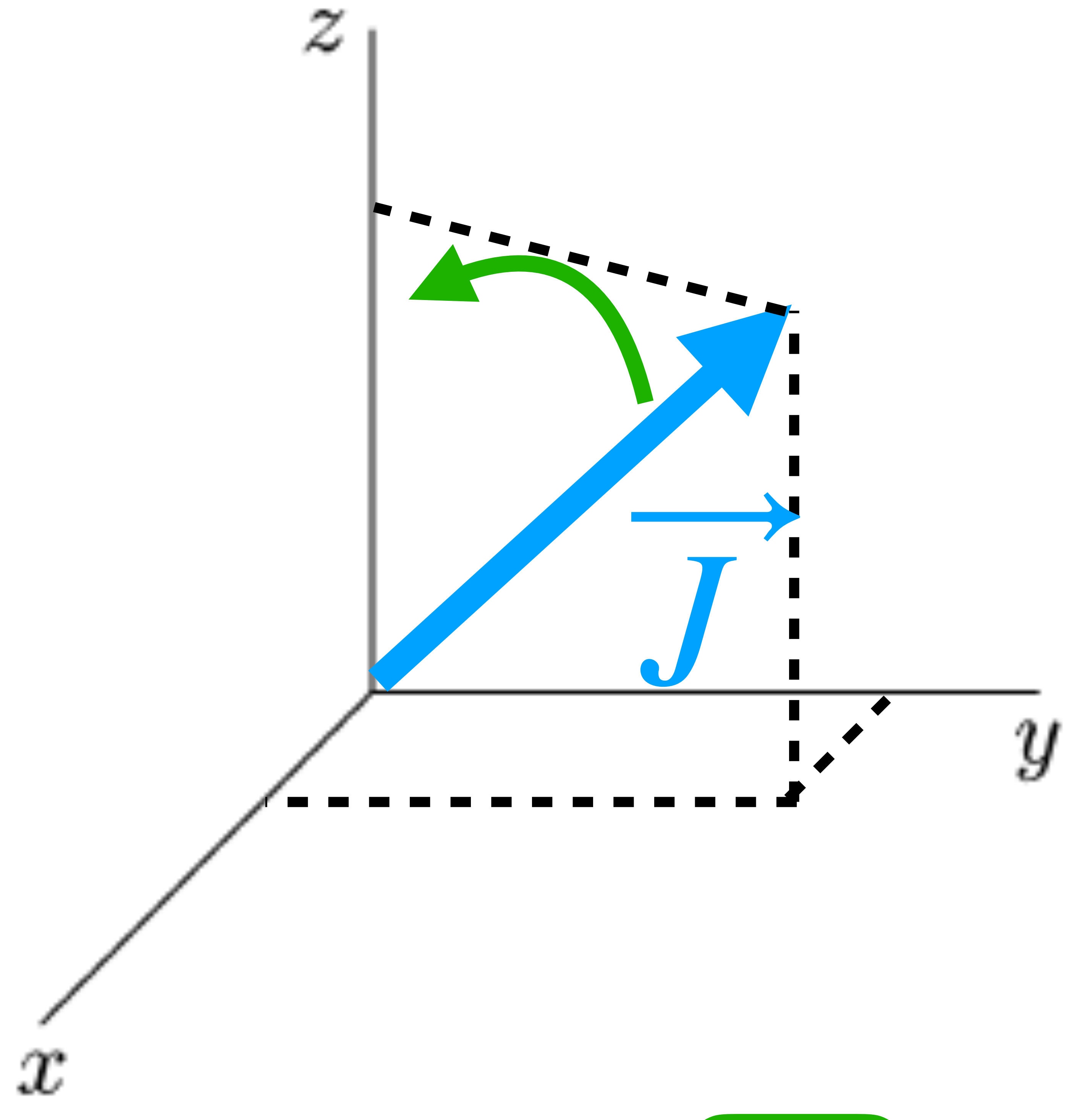
Magnetic moments

Electromagnetic observables



What is measured

$$\mu = \langle J, J_z = J \,|\, \mu_z \,|\, J, J_z = J \rangle$$



$$\hat{H} \to \hat{H} - \boxed{B_z} \hat{J}_z$$

A.G., B. Fore, A. Lovato, and A. Tropiano, arXiv:2308.16266 (2023)

Beta decay (preliminary)

PROCESS	Gamow-Teller		Experiment
	NQS	HH	
$^3\mathrm{H} \rightarrow {}^3\mathrm{He} + e^- + \bar{\nu}$	0.9723(13)	0.9720(4)	0.9511(13)
$^7\mathrm{Be} + e^- \rightarrow {}^7\mathrm{Li} + \nu$	2.510(3)	–	2.3556(47)

$$\langle \hat{O} \rangle = \frac{\langle \psi_f | \hat{O} | \psi_i \rangle}{\sqrt{\langle \psi_f | \psi_f \rangle \langle \psi_i | \psi_i \rangle}}$$

First calculation of electroweak properties using Neural Network quantum states

Next goal: super-allowed beta decay

Summary

A look in the next future

- New wave function construction (faster and better convergence)
- Expansion to multinode GPUs (recent results for A=40 nuclei)
- High precision nuclear forces
- … and many more

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