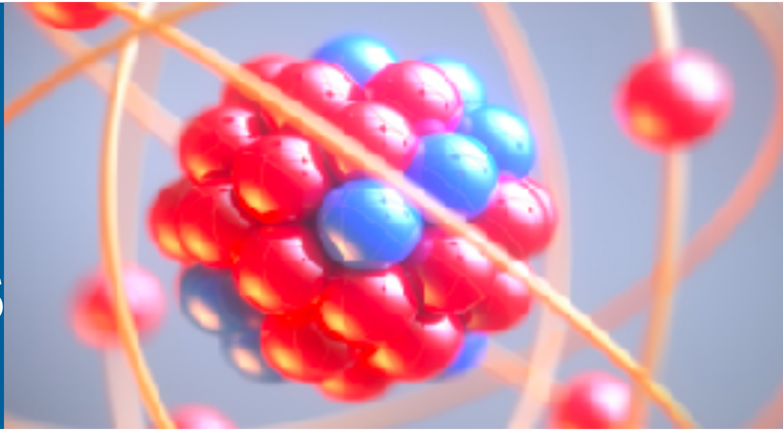
NUCLEI AND NUCLEONIC MATTER WITH NEURAL-NETWORK QUANTUM STATES



ALESSANDRO LOVATO

Workshop on Progress in Ab Initio Nuclear Theory

TRIUMF, Vancouver, BC

Argonne NATIONAL LABORATORY

February 28, 2024

COLLABORATORS

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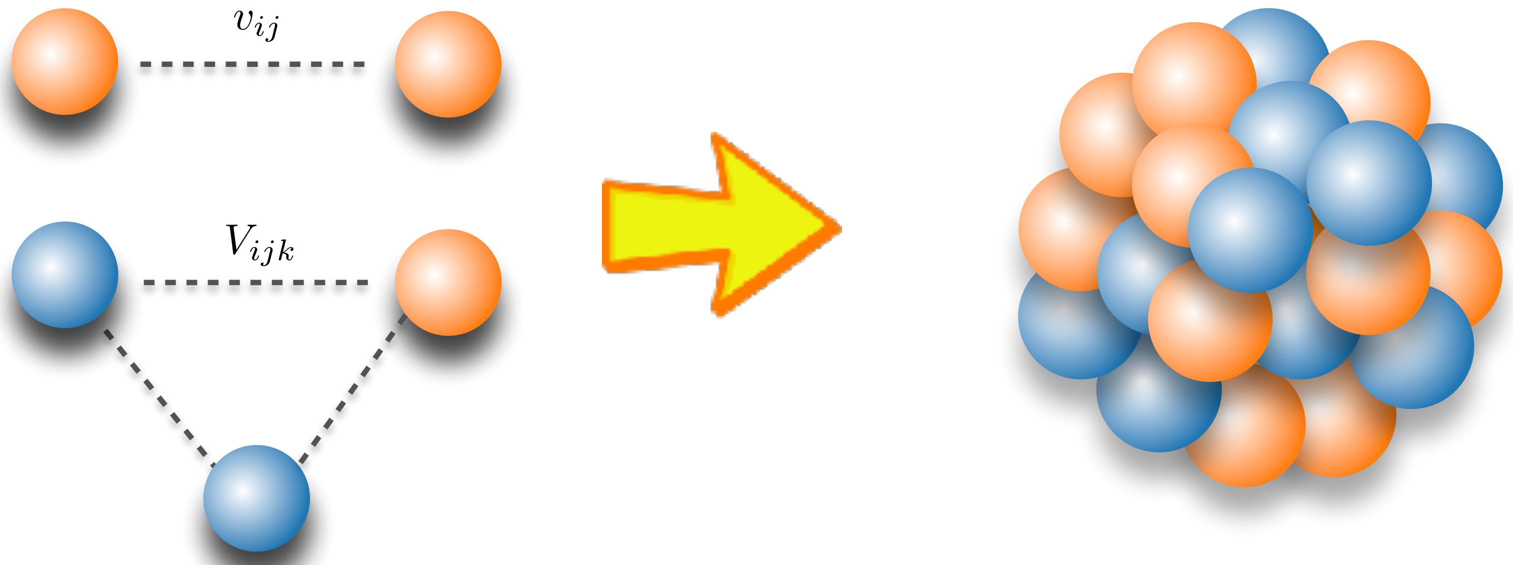
THE QUANTUM MANY-BODY PROBLEM

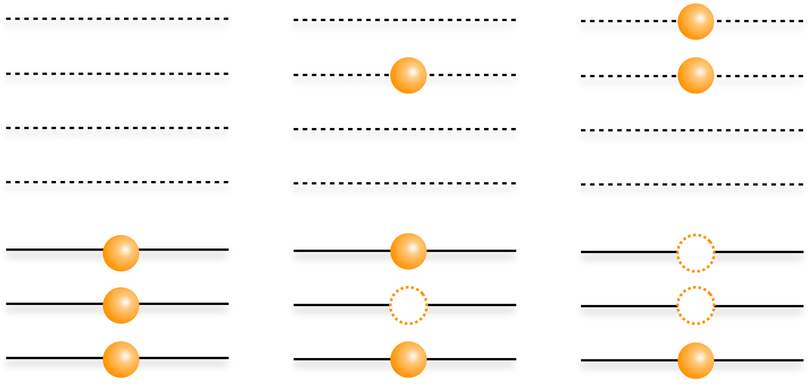
$$H = \sum_i \frac{p_i^2}{2m} + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk}$$

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

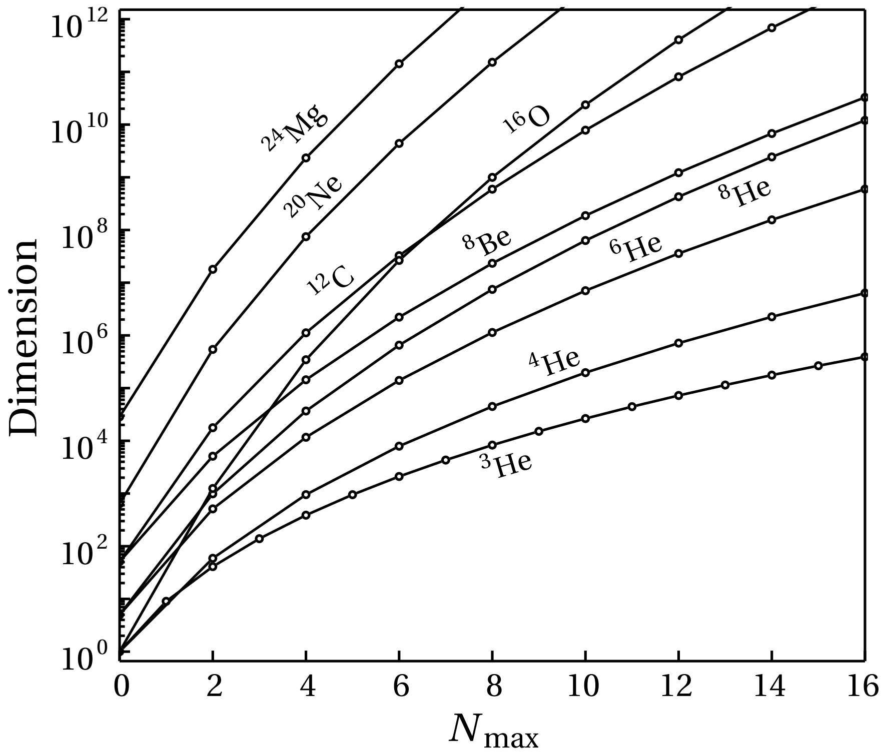


CONFIGURATION-INTERACTION METHODS

$$\Psi_0(x_1, \ldots, x_A) = \sum_n c_n \Phi_n(x_1, \ldots, x_A)$$



$|\Phi_0\rangle$ $|\Phi_{h_2}^{p_3}\rangle$ $|\Phi_{h_2h_3}^{p_3p_4}\rangle$



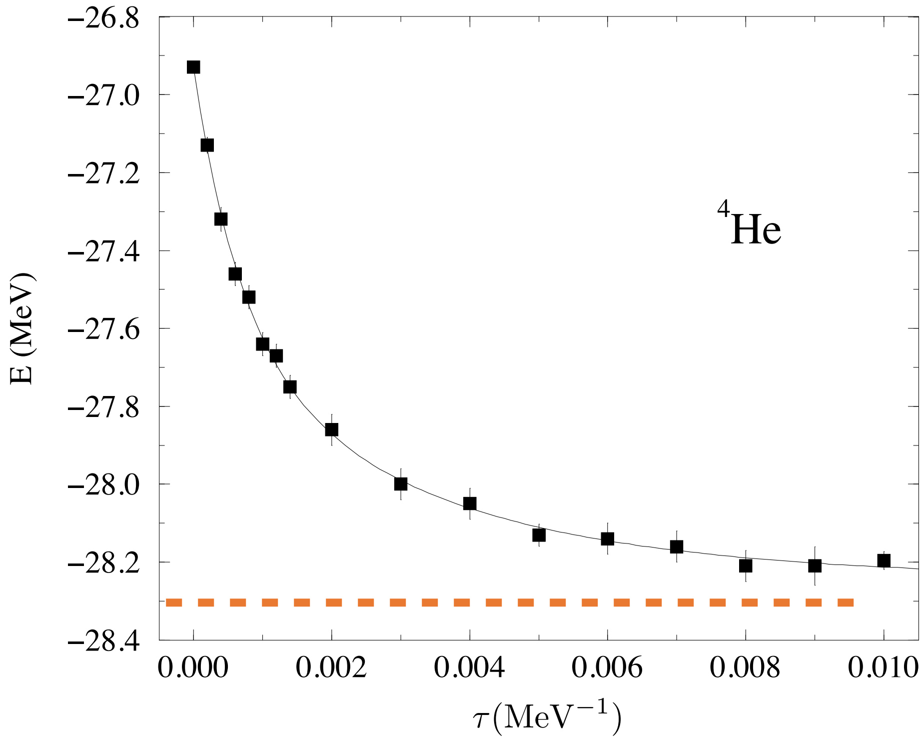
GREEN'S FUNCTION MONTE CARLO

The GFMC projects out the lowest-energy state using an imaginary-time propagation

$$|\Psi_V\rangle = \sum_n c_n |\Psi_n\rangle \quad ; \quad H_n|\Psi_n\rangle = E_n|\Psi_n\rangle$$

$$\lim_{\tau\to\infty} e^{-(H-E_0)\tau}|\Psi_V\rangle =$$

$$= \sum_n c_n e^{-(E_n-E_0)\tau}|\Psi_n\rangle = c_0|\Psi_0\rangle$$

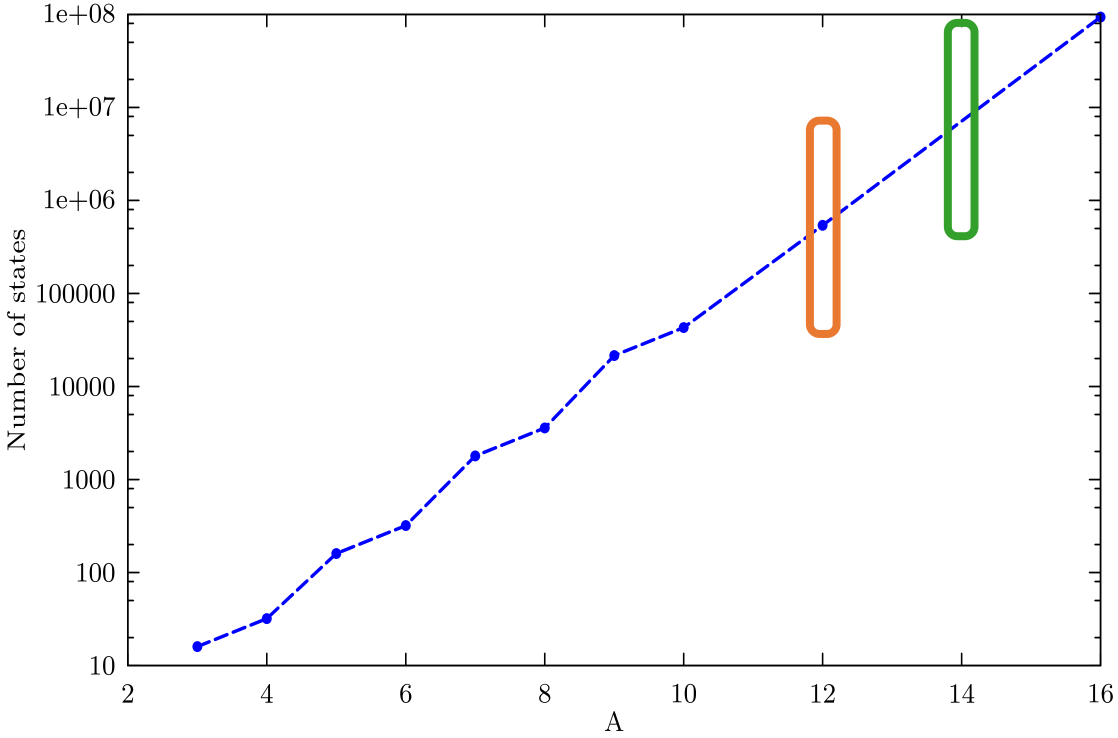


*J. Carlson Phys. Rev. C **36**, 2026 (1987)*

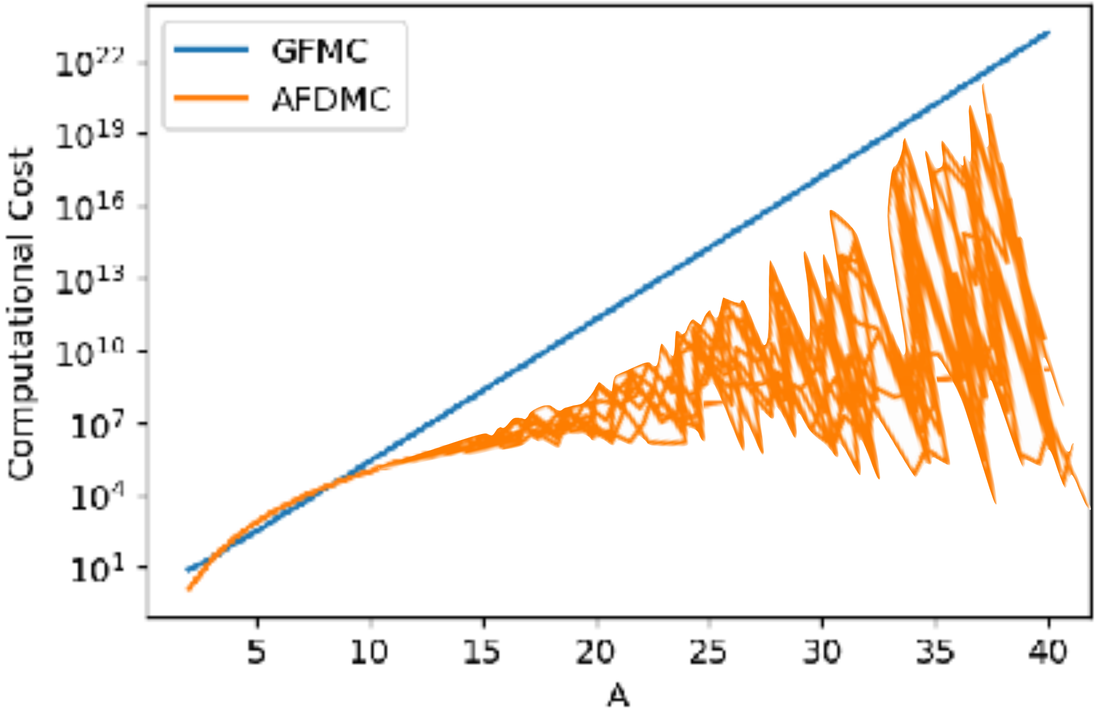
*B. Pudliner et al., PRC **56**, 1720 (1997)*

CONVENTIONAL QUANTUM MONTE CARLO

$$\langle \mathbf{R}|\Psi(\tau)\rangle = \begin{pmatrix} a_{\uparrow\uparrow\uparrow}(\mathbf{R}) \\ a_{\downarrow\uparrow\uparrow}(\mathbf{R}) \\ a_{\uparrow\downarrow\uparrow}(\mathbf{R}) \\ a_{\downarrow\downarrow\uparrow}(\mathbf{R}) \\ a_{\uparrow\uparrow\downarrow}(\mathbf{R}) \\ a_{\downarrow\uparrow\downarrow}(\mathbf{R}) \\ a_{\uparrow\downarrow\downarrow}(\mathbf{R}) \\ a_{\downarrow\downarrow\downarrow}(\mathbf{R}) \end{pmatrix}$$



HOW TO TACKLE (EVEN) LARGER NUCLEI?



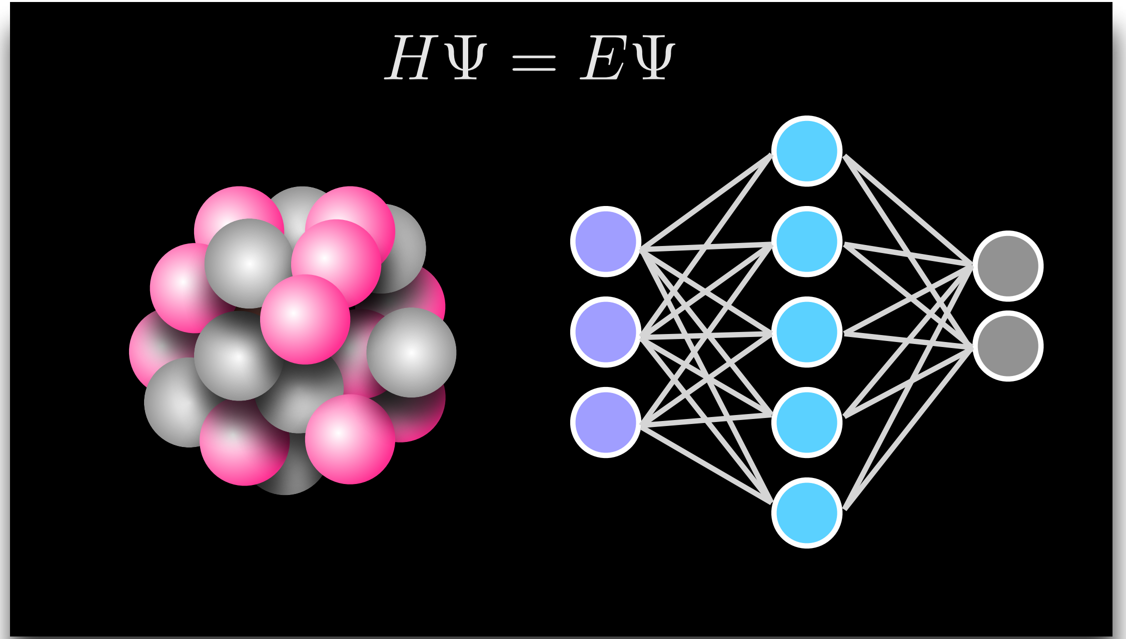
GFMC

$$|\Psi_T\rangle \sim \prod_{i<j} F_{ij}|\Phi\rangle$$

AFDMC

$$|\Psi_T\rangle \sim (1 + \sum_{i<j} F_{ij})|\Phi\rangle$$

NEURAL NETWORK QUANTUM STATES



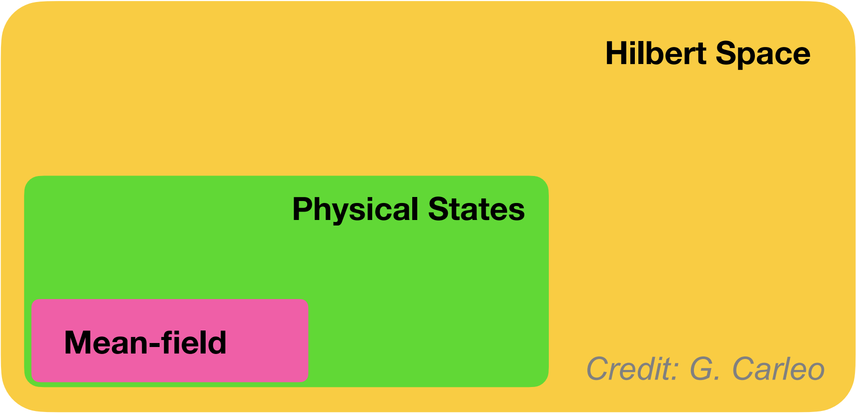
NEURAL-NETWORK QUANTUM STATES

$$H_{TIF} = -h \sum_i \sigma_i^x - \sum_{\langle i,j \rangle} \sigma_i^z \sigma_j^z$$

Finding the exact ground-state is, in principle, **exponentially hard**

$$|\Psi\rangle = c_{\uparrow\uparrow\uparrow\ldots} | \uparrow\uparrow\uparrow \ldots \rangle + c_{\downarrow\uparrow\uparrow\ldots} | \downarrow\uparrow\uparrow \ldots \rangle + \cdots + c_{\downarrow\downarrow\downarrow\ldots} | \downarrow\downarrow\downarrow \ldots \rangle$$

Quantum states of physical interest have distinctive features and intrinsic structures

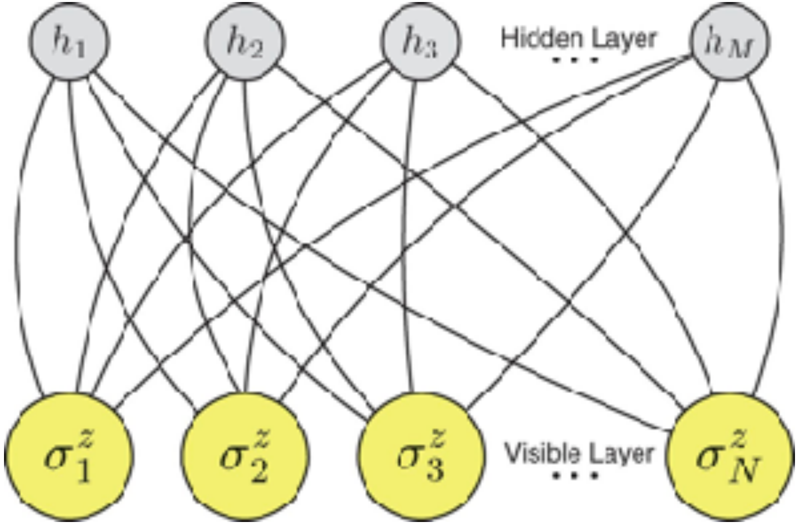


NEURAL-NETWORK QUANTUM STATES

$$\left\{\begin{array}{l} c_{\uparrow\uparrow\uparrow\ldots} \equiv \langle\uparrow\uparrow\uparrow\ldots|\Psi\rangle \equiv \Psi(\uparrow\uparrow\uparrow\ldots) \\ c_{\downarrow\uparrow\uparrow\ldots} \equiv \langle\downarrow\uparrow\uparrow\ldots|\Psi\rangle \equiv \Psi(\downarrow\uparrow\uparrow\ldots) \\ \\ c_{\downarrow\downarrow\downarrow\ldots} \equiv \langle\downarrow\downarrow\downarrow\ldots|\Psi\rangle \equiv \Psi(\downarrow\downarrow\downarrow\ldots) \end{array}\right. \quad \longleftrightarrow \quad c_S \equiv \langle S|\Psi\rangle \equiv \Psi(S)$$

Idea: use neural networks to represent the quantum many-body wave function

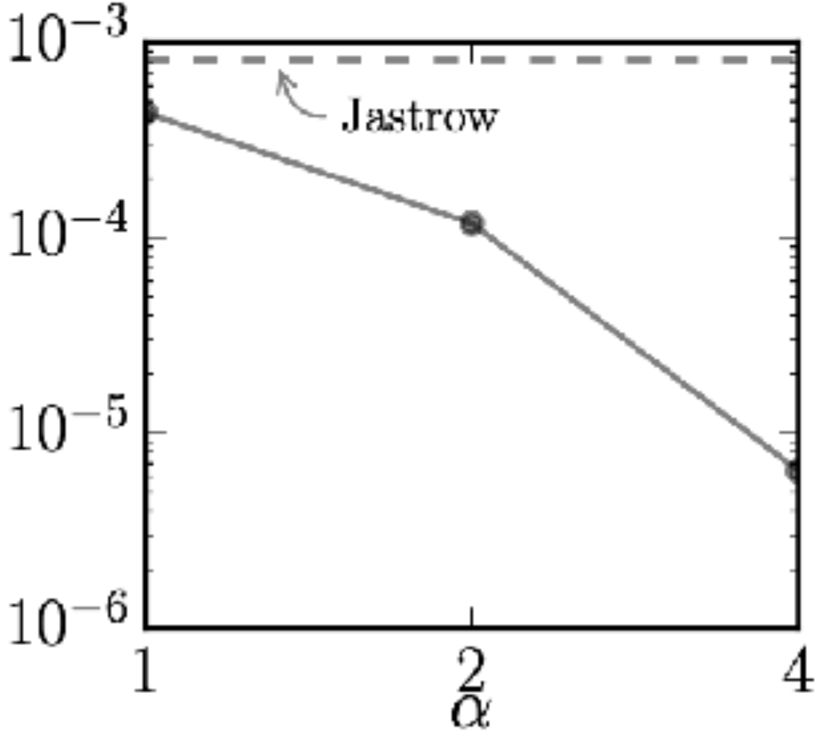
$$\hat{\Psi}(S) = \sum_{h_i=0,1} e^{\sum_j a_j \sigma_j^z + \sum_i b_i h_i + \sum_{ij} W_{ij} h_i \sigma_j}$$



G. Carleo et al. Science ***355****, 602 (2017)*

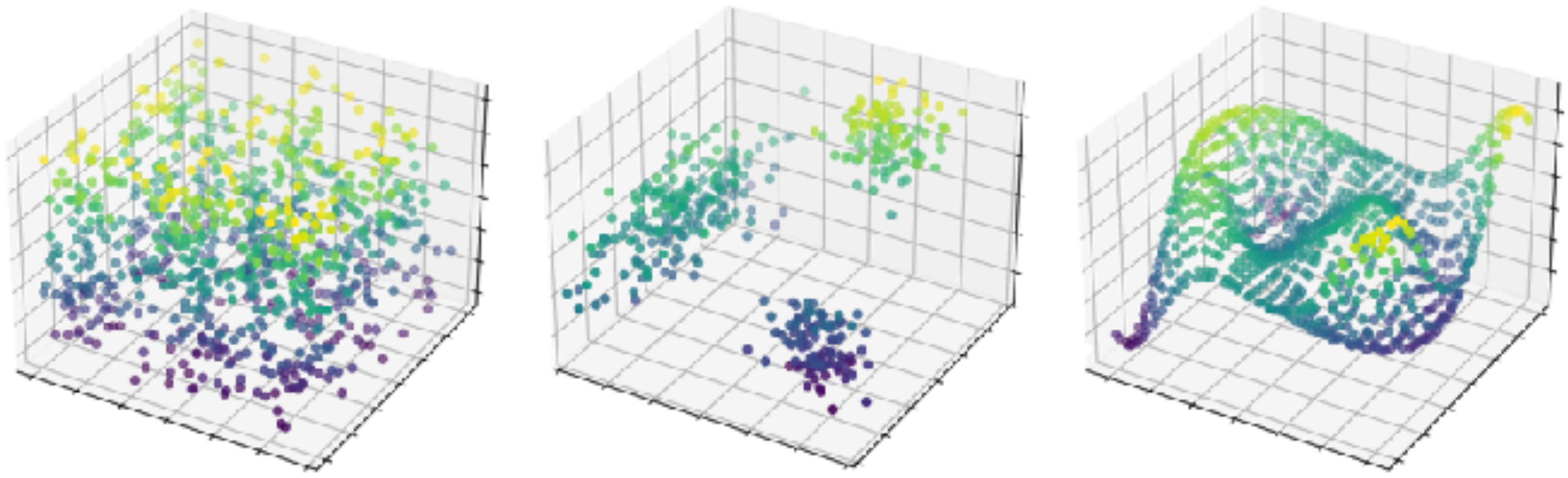
NEURAL-NETWORK QUANTUM STATES

G. Carleo and M. Troyer proved that Restricted Boltzmann machines outperform traditional Jastrow



G. Carleo et al. Science ***355****, 602 (2017)*

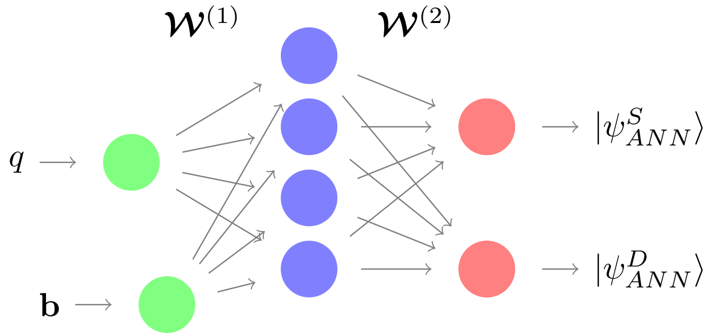
NEURAL-NETWORK QUANTUM STATES



Credit: J. Kim

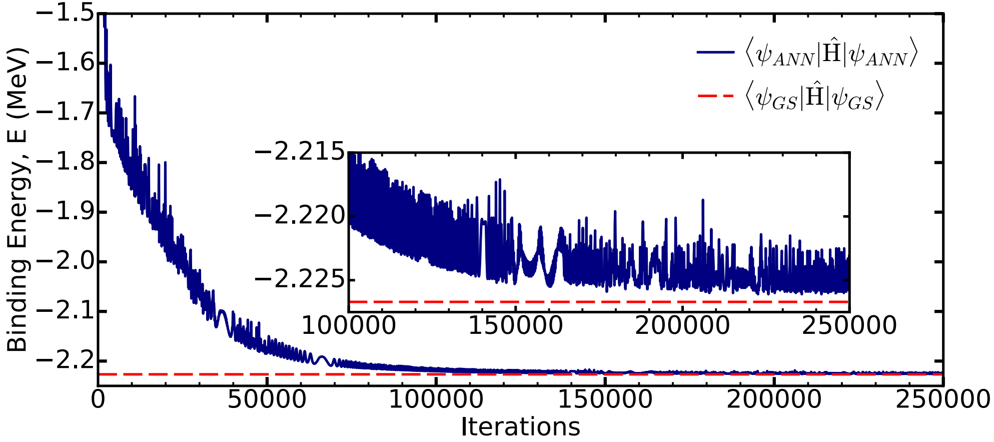
MACHINE-LEARNING THE DEUTERON

ANNs solve the deuteron using the N3LO Entem-Machleidt chiral-EFT NN potential



The parameters of the ANN are optimized minimizing the variational energy using RMSprop

$$E^{\mathcal{W}} = \frac{\left\langle \Psi^{\mathcal{W}}_{\text{ANN}} \right| \hat{H} \left| \Psi^{\mathcal{W}}_{\text{ANN}} \right\rangle}{\left\langle \Psi^{\mathcal{W}}_{\text{ANN}} \middle| \Psi^{\mathcal{W}}_{\text{ANN}} \right\rangle}$$



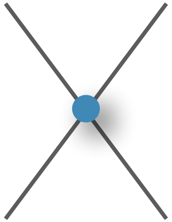
*Keeble, Rios, PLB **809**, 135743 (2020)*

PIONLESS EFT HAMILTONIAN

We take as input a LO pionless-EFT Hamiltonian

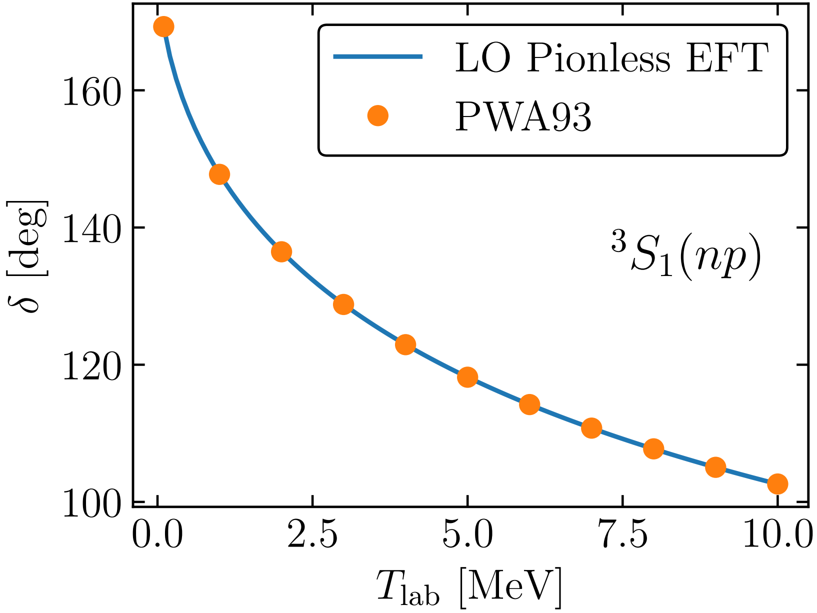
$$H_{LO} = -\sum_i \frac{\vec{\nabla}_i^2}{2m_N} + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk}$$

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



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

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



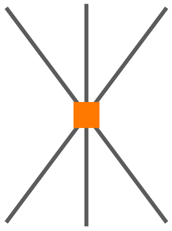
*R. Schiavilla, AL, PRC **103**, 054003 (2021)*

PIONLESS EFT HAMILTONIAN

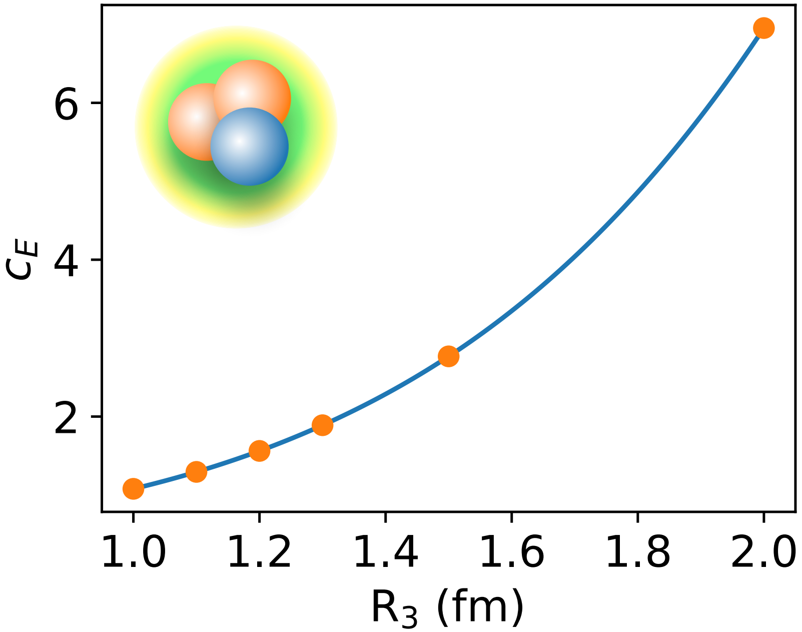
We take as input a LO pionless-EFT Hamiltonian

$$H_{LO} = -\sum_i \frac{\vec{\nabla}_i^2}{2m_N} + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk}$$

- 3NF adjusted to reproduce the energy of ^{3}H.



$$V_{ijk} \propto c_E \sum_{\rm cyc} e^{-(r_{ij}^2 + r_{jk}^2)/R_3^2}$$



*R. Schiavilla, AL, PRC **103**, 054003 (2021)*

NEURAL SLATER-JASTROW ANSATZ

Product of mean-field state modulated by a flexible correlator factor

$$\Psi_{SJ}(X) = e^{J(X)}\Phi(X)$$

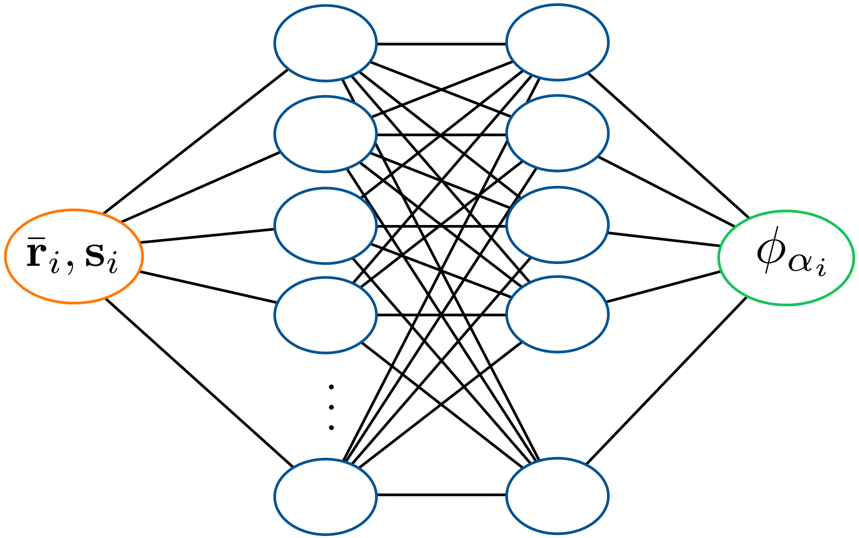
NEURAL SLATER-JASTROW ANSATZ

Product of mean-field state modulated by a flexible correlator factor

$$\Psi_{SJ}(X) = e^{J(X)}\Phi(X)$$

Mean-field: Slater determinant of single-particle orbitals

$$\det\begin{bmatrix} \phi_1(\mathbf{x}_1) & \phi_1(\mathbf{x}_2) & \cdots & \phi_1(\mathbf{x}_N) \\ \phi_2(\mathbf{x}_1) & \phi_2(\mathbf{x}_2) & \cdots & \phi_2(\mathbf{x}_N) \\ \vdots & \vdots & \ddots & \vdots \\ \phi_N(\mathbf{x}_1) & \phi_N(\mathbf{x}_2) & \cdots & \phi_N(\mathbf{x}_N) \end{bmatrix}$$



Each orbital is a FFNN that takes as input

$$\bar{\mathbf{r}}_i = \mathbf{r}_i - \mathbf{R}_{CM}$$

NEURAL SLATER-JASTROW ANSATZ

“Manually” imposing permutation-invariance scales factorially with A

$$J(X) = j(x_1, x_2, x_3) + j(x_1, x_3, x_2) + j(x_2, x_1, x_3) + j(x_2, x_3, x_1) + j(x_3, x_1, x_2) + j(x_3, x_2, x_1)$$

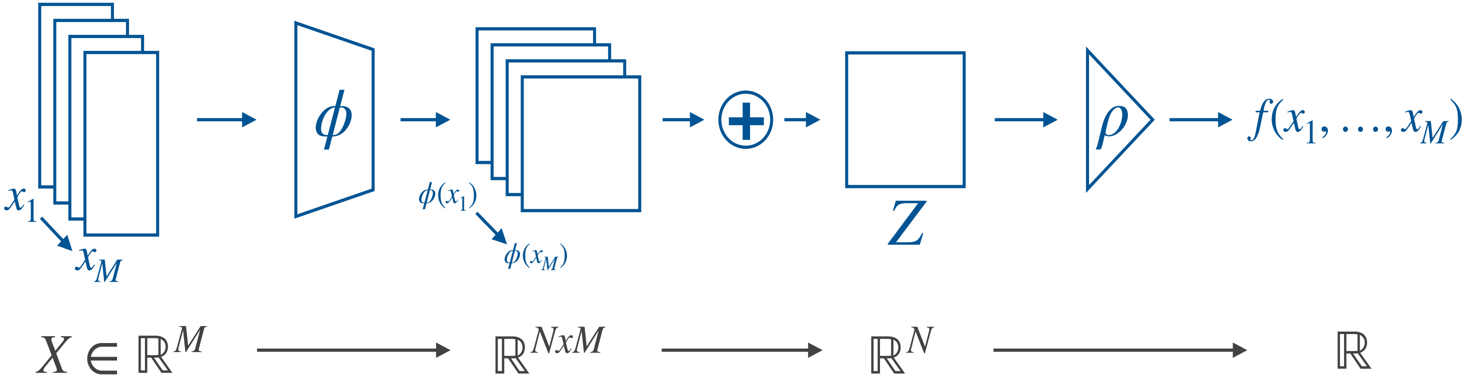
NEURAL SLATER-JASTROW ANSATZ

“Manually” imposing permutation-invariance scales factorially with A

$$J(X) = j(x_1, x_2, x_3) + j(x_1, x_3, x_2) + j(x_2, x_1, x_3) + j(x_2, x_3, x_1) + j(x_3, x_1, x_2) + j(x_3, x_2, x_1)$$

Solution: “deep-sets” →

$$J(X) = \rho_F \left[\sum_i \vec{\phi}_{\mathcal{F}}(\bar{\mathbf{r}}_i, \mathbf{s}_i) \right]$$



SAMPLING COORDINATES AND SPIN

$$E_V = \frac{\langle \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} = \frac{\sum_S \int dR |\Psi_V(R,S)|^2 \frac{\langle RS|H|\Psi_V \rangle}{\langle RS|\Psi_V \rangle}}{\sum_S \int dR |\Psi_V(R,S)|^2} .$$

Markov Chain Mote Carlo algorithm to sample the Hilbert space

$$P_{\text{acc}} = \min \left(1, \frac{|\Psi_V(R', S')|^2}{|\Psi_V(R,S)|^2} \right)$$

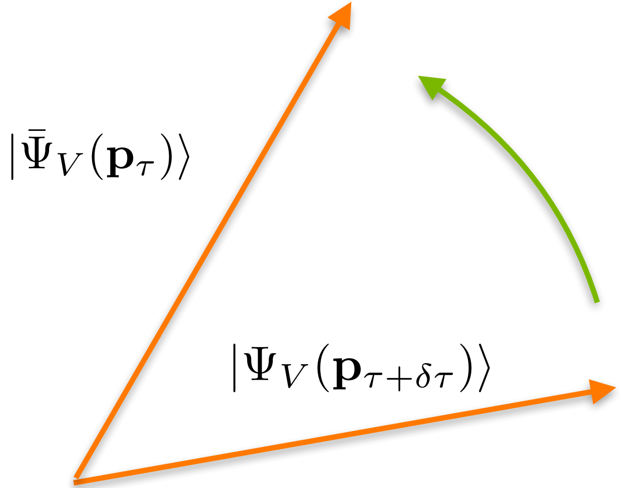
Observables estimated by averaging over the sampled configurations

$$\frac{\langle \Psi_V | H | \Psi_V \rangle}{\langle \Psi_V | \Psi_V \rangle} \simeq \frac{1}{N} \sum_{R,S} \frac{\langle R, S | H | \Psi_V \rangle}{\langle R, S | \Psi_V \rangle}$$

WAVE FUNCTION OPTIMIZATION

ANN trained by performing an imaginary-time evolution in the variational manifold

$$
\begin{cases}
|\bar{\Psi}_V(\mathbf{p}_\tau\rangle \equiv (1 - H\delta\tau)|\Psi_V(\mathbf{p}_\tau)\rangle \\
\mathbf{p}_{\tau+\delta\tau} = \underset{\mathbf{p}\in R^d}{\arg\max} \left(\left| \langle \bar{\Psi}_V(\mathbf{p}_\tau) | \Psi_V(\mathbf{p}_{\tau+\delta\tau}) \rangle \right|^2 \right)
\end{cases}
$$



The parameters are updated as

$$
\mathbf{p}_{\tau+\delta\tau} = \mathbf{p}_\tau - \delta\tau S^{-1}\mathbf{g}_\tau
$$

J. Stokes, at al., Quantum 4, 269 (2020).

S. Sorella, Phys. Rev. B 64, 024512 (2001)

WAVE FUNCTION OPTIMIZATION

ANN trained by performing an imaginary-time evolution in the variational manifold

See Mehdi Drissi's talk on Friday

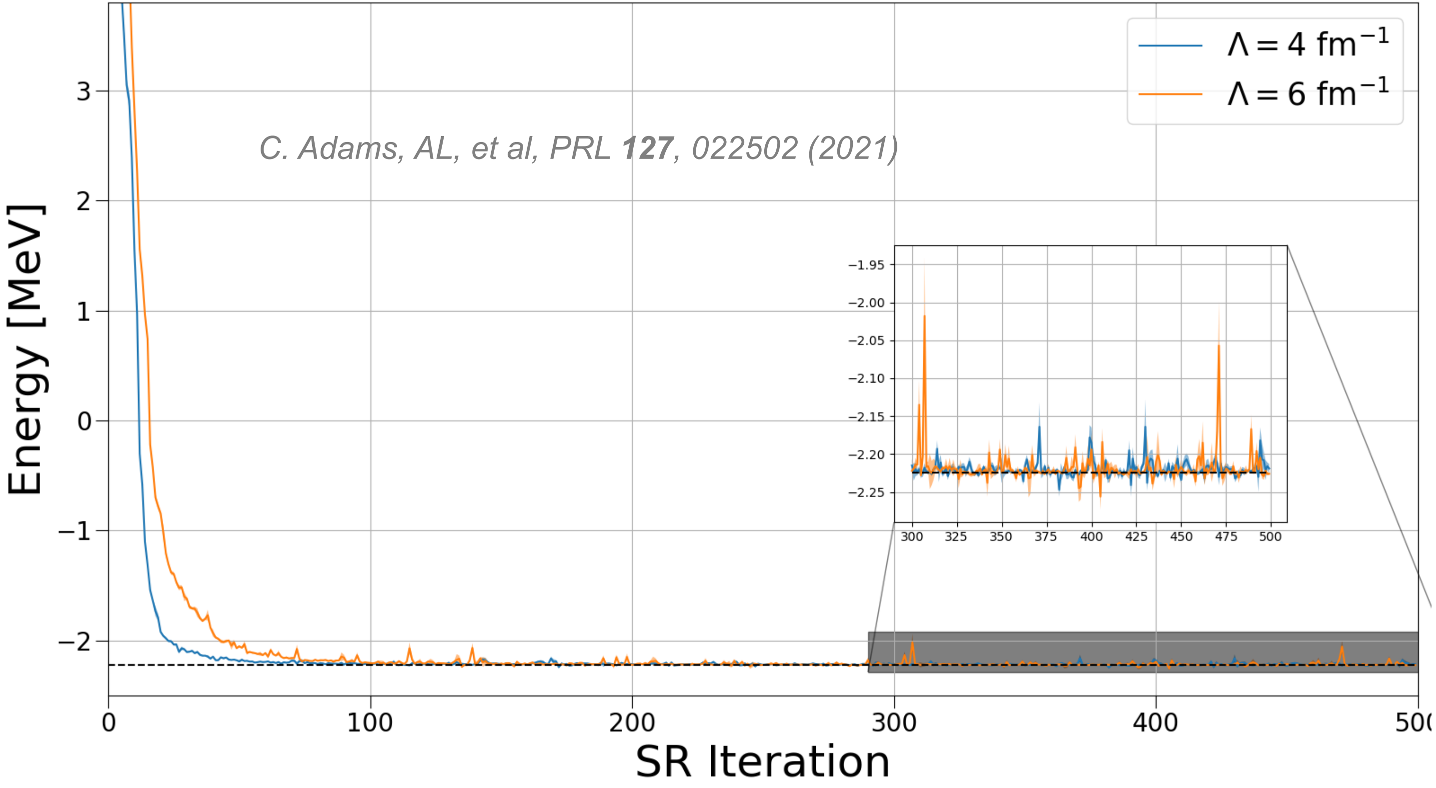
The parameters are updated as

$$\mathbf{p}_{\tau+\delta\tau} = \mathbf{p}_{\tau} - \delta\tau S^{-1}\mathbf{g}_{\tau}$$

J. Stokes, at al., Quantum 4, 269 (2020).

S. Sorella, Phys. Rev. B 64, 024512 (2001)

STOCHASTIC RECONFIGURATION



COMPARISON WITH GFMC

- The ANN Slater Jastrow ansatz outperforms conventional Jastrow correlations

	Λ	VMC-ANN	VMC-JS	GFMC	GFMC_c
^{2}H	4 fm^{-1}	−2.224(1)	−2.223(1)	−2.224(1)	-
	6 fm^{-1}	−2.224(4)	−2.220(1)	−2.225(1)	-
^{3}H	4 fm^{-1}	−8.26(1)	−7.80(1)	−8.38(2)	−7.82(1)
	6 fm^{-1}	−8.27(1)	−7.74(1)	−8.38(2)	−7.81(1)
^{4}He	4 fm^{-1}	−23.30(2)	−22.54(1)	−23.62(3)	−22.77(2)
	6 fm^{-1}	−24.47(3)	−23.44(2)	−25.06(3)	−24.10(2)

- Differences with the GFMC due to deficiencies in the Slater-Jastrow ansatz

$$\Psi_{SJ}(X) = e^{J(X)}\Phi(X)$$

C. Adams, AL, et al, PRL **127**, 022502 (2021)

HIDDEN NUCLEONS ANSATZ

$$\Phi(X) = \det \begin{bmatrix} \phi_1(x_1) & \phi_1(x_2) & \phi_1(x_3) & \phi_1(x_4) \\ \phi_2(x_1) & \phi_2(x_2) & \phi_2(x_3) & \phi_2(x_4) \\ \phi_3(x_1) & \phi_3(x_2) & \phi_3(x_3) & \phi_3(x_4) \\ \phi_4(x_1) & \phi_4(x_2) & \phi_4(x_3) & \phi_4(x_4) \end{bmatrix}$$

HIDDEN NUCLEONS ANSATZ

$$\Psi_{\mathrm{HN}}(X) = \det \begin{bmatrix} \phi_1(x_1) & \phi_1(x_2) & \phi_1(x_3) & \phi_1(x_4) & \phi_1(y_1) & \phi_1(y_2) \\ \phi_2(x_1) & \phi_2(x_2) & \phi_2(x_3) & \phi_2(x_4) & \phi_2(y_1) & \phi_1(y_2) \\ \phi_3(x_1) & \phi_3(x_2) & \phi_3(x_3) & \phi_3(x_4) & \phi_3(y_1) & \phi_1(y_2) \\ \phi_4(x_1) & \phi_4(x_2) & \phi_4(x_3) & \phi_4(x_4) & \phi_4(y_1) & \phi_1(y_2) \\ \chi_1(x_1) & \chi_1(x_2) & \chi_1(x_3) & \chi_1(x_4) & \chi_1(y_1) & \chi_2(y_2) \\ \chi_2(x_1) & \chi_2(x_2) & \chi_2(x_3) & \chi_2(x_4) & \chi_2(y_1) & \chi_2(y_2) \end{bmatrix}$$

Visible orbitals on visible coordinates

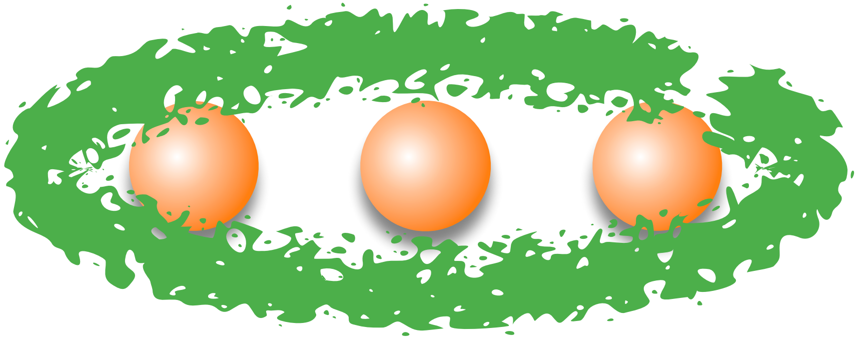
Visible orbitals on hidden coordinates

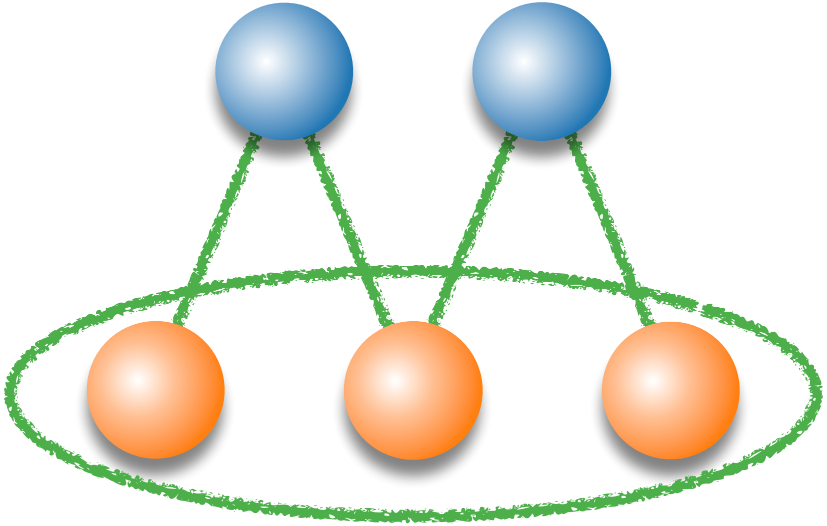
Hidden orbitals on visible coordinates

Hidden orbitals on hidden coordinates

*J. R. Moreno, et al., PNAS **119,** 2122059119(2022)*

HIDDEN NUCLEONS ANSATZ

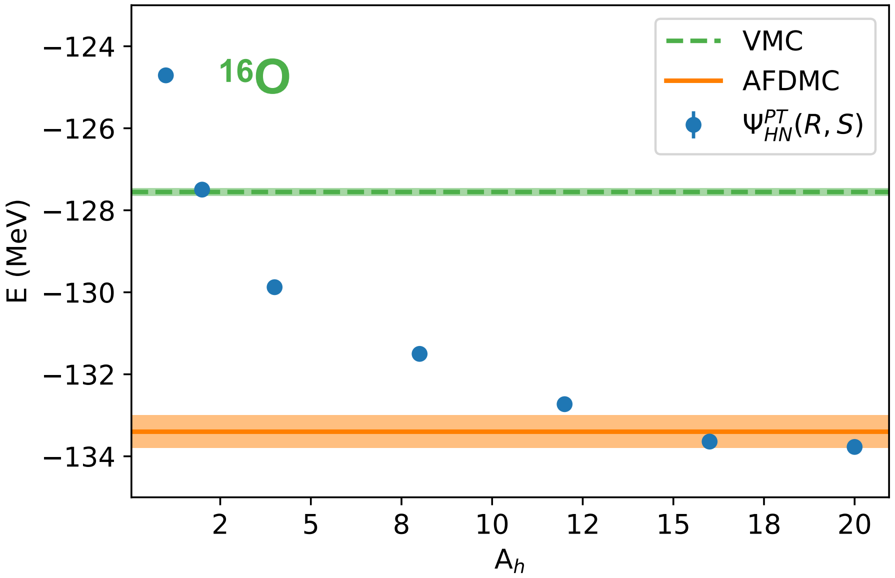


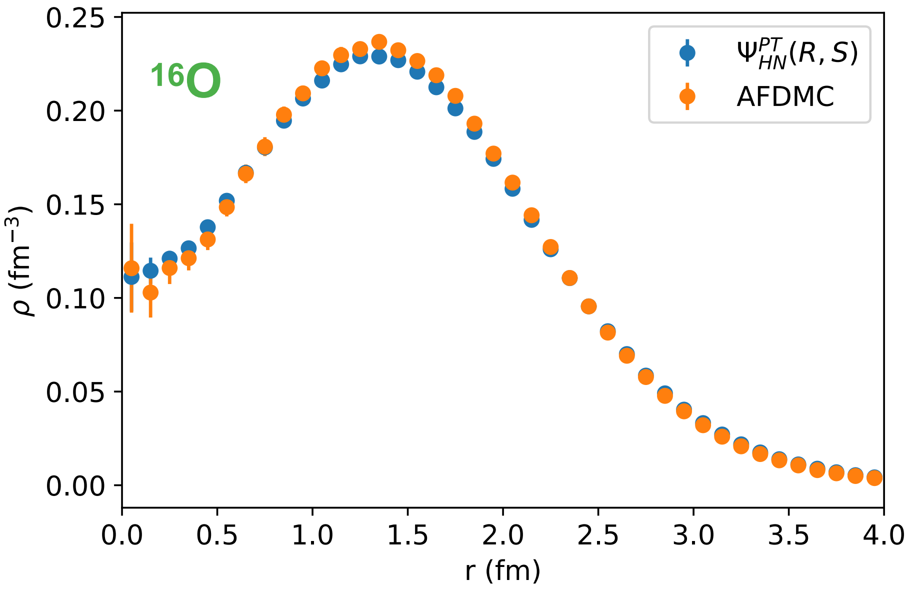


HIDDEN NUCLEONS ANSATZ

We extend the reach of neural quantum states to ^{16}O

In addition to its ground-state energy, we evaluate the point-nucleon density of ^{16}O with A_h=16





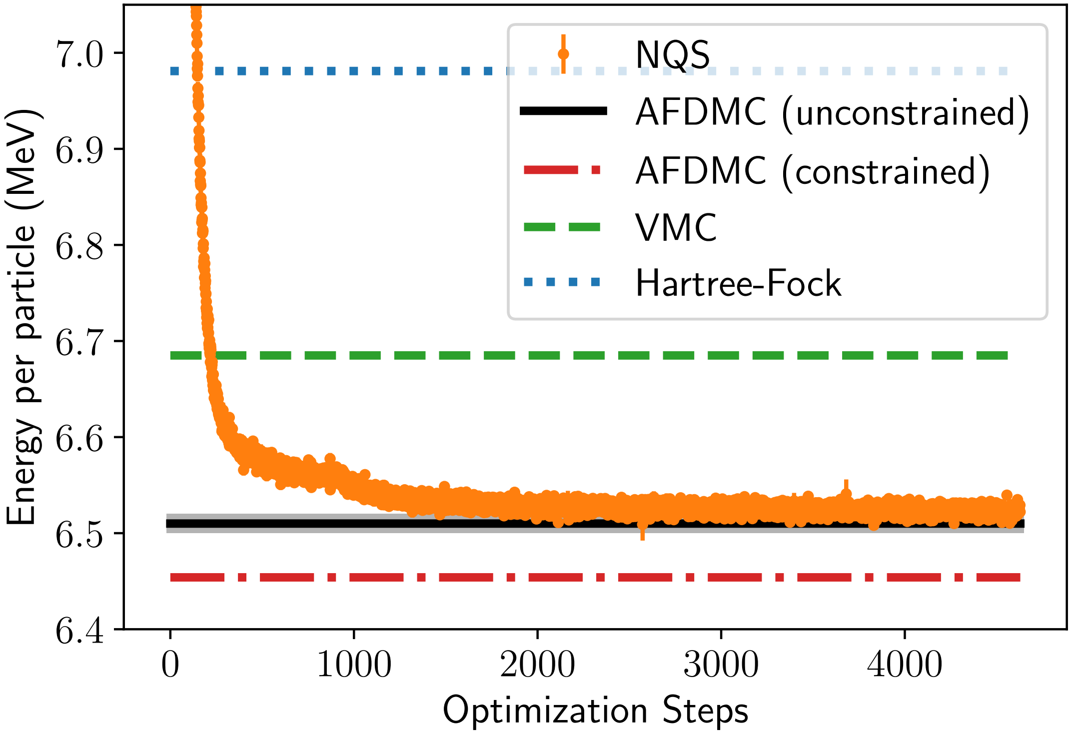
AL, et al., Phys. Rev. Res. ***4*** *(2022) 4, 043178*

DILUTE NEUTRON MATTER

Periodic hidden-nucleons ansatz to model low-density neutron matter

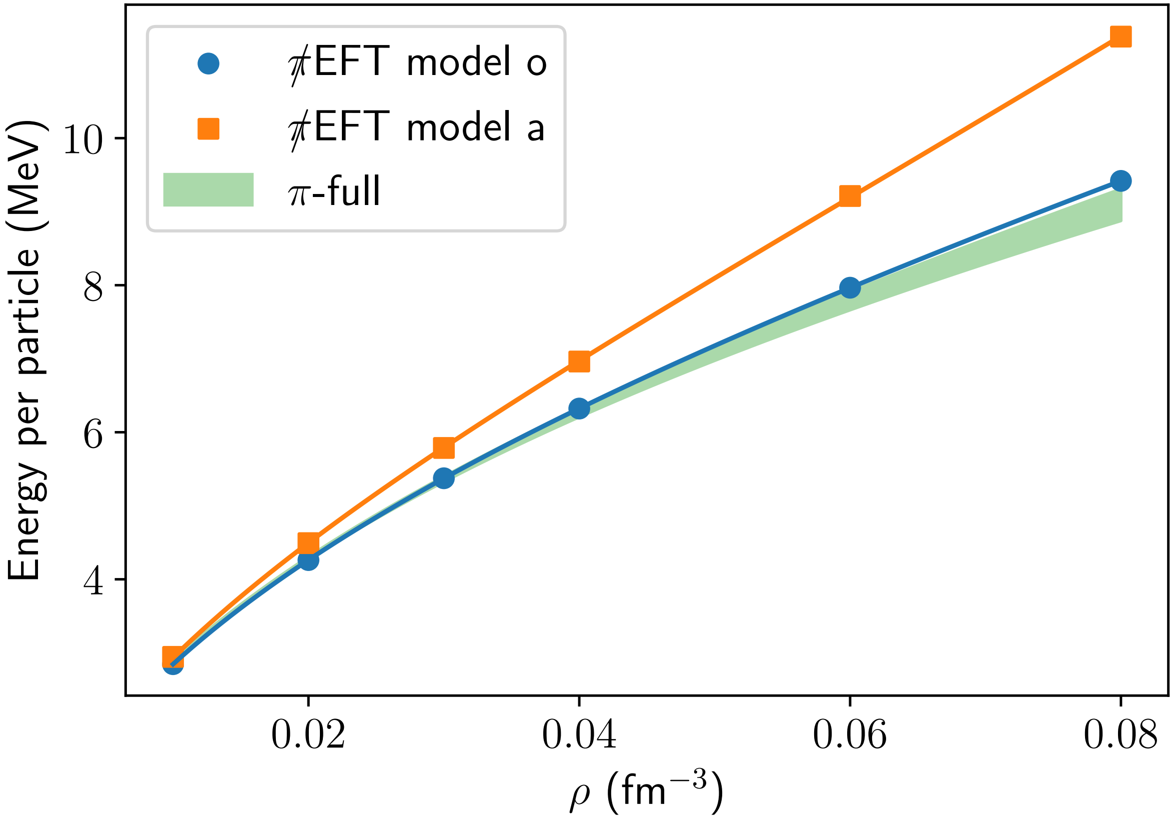
- **NQS**: 100 GPU hours
- **AFDMC**: 1.2 million CPU hours

14 Neutrons @ ρ=0.04 fm^{-3}



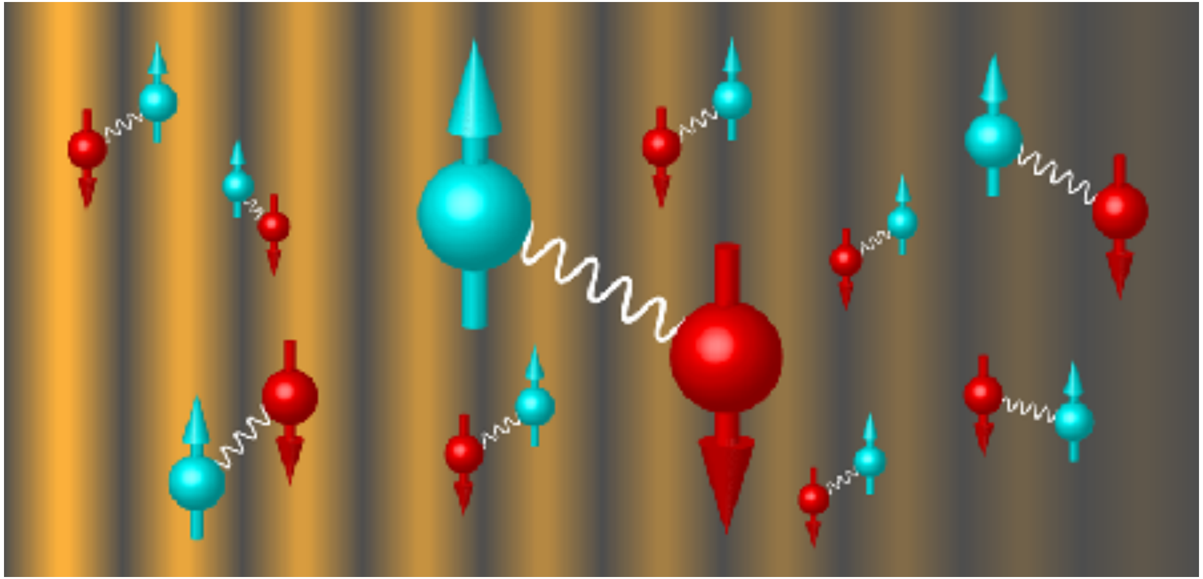
B. Fore, AL et al., Phys. Rev. Res. ***5****, 033062 (2023)*

DILUTE NEUTRON MATTER



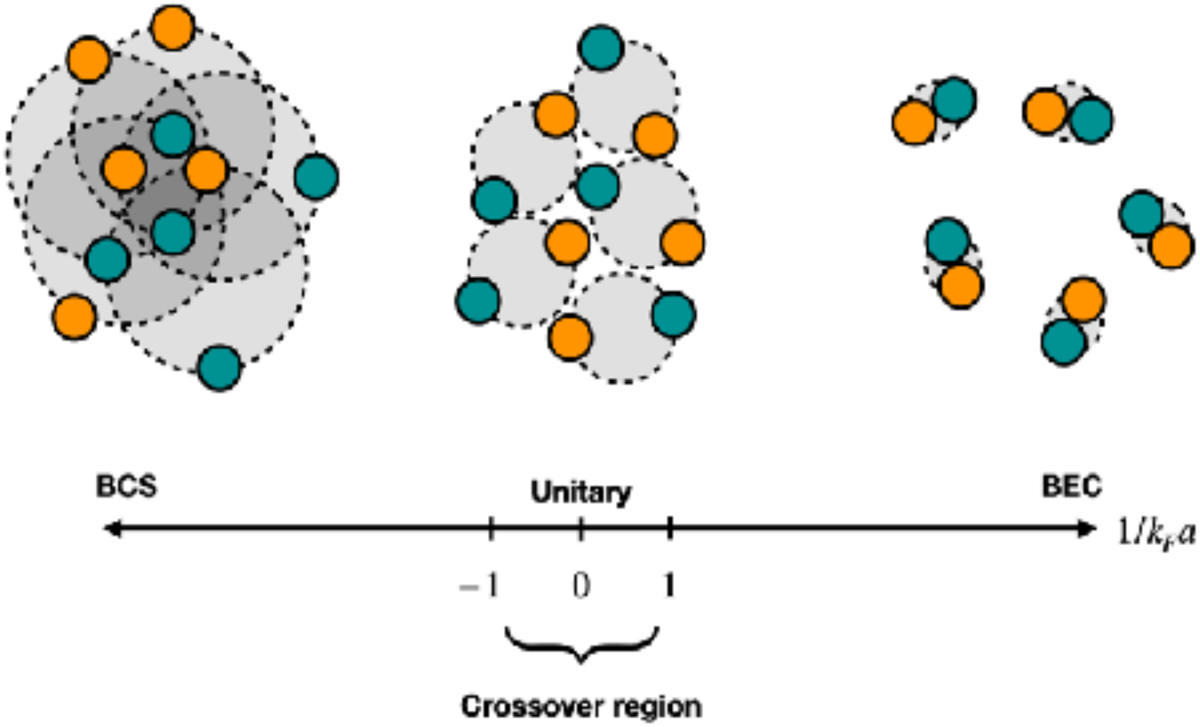
B. Fore, AL et al., Phys. Rev. Res. ***5****, 033062 (2023)*

CONDENSED-MATTER DETOUR



COLD FERMI GASES

Periodic-NQS to solve the two-components Fermi gas in the BCS- BEC crossover region



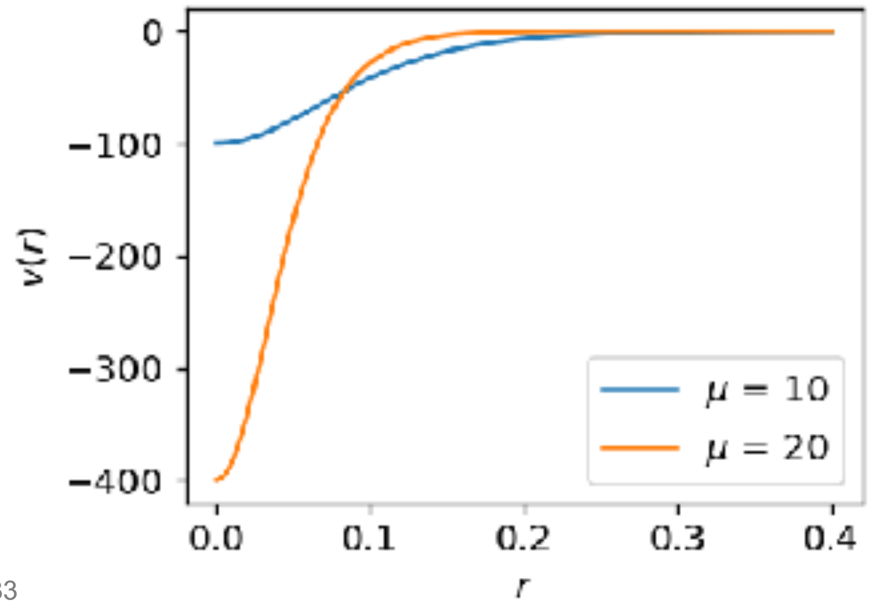
COLD FERMI GASES

We model the 3D unpolarized gas of fermions with the Hamiltonian

$$H = \sum_i \frac{p_i^2}{2m} + \sum_{i<j} v_{ij}$$

- Modified Pöschl-Teller potential between opposite-spin particles

$$v_{ij} = (\delta_{s_i,s_j} - 1) v_0 \frac{2\hbar^2}{m} \frac{\mu^2}{\cosh^2(\mu r_{ij})}$$



COLD FERMI GASES

We introduce a Pfaffian-Jastrow ansatz

$$\Phi_{PJ}(X) = \text{pf}\begin{bmatrix} 0 & \phi(x_1, x_2) & \cdots & \phi(x_1, x_N) \\ \phi(x_2, x_1) & 0 & \cdots & \phi(x_2, x_N) \\ \vdots & \vdots & \ddots & \vdots \\ \phi(x_N, x_1) & \phi(x_N, x_2) & \cdots & 0 \end{bmatrix}$$

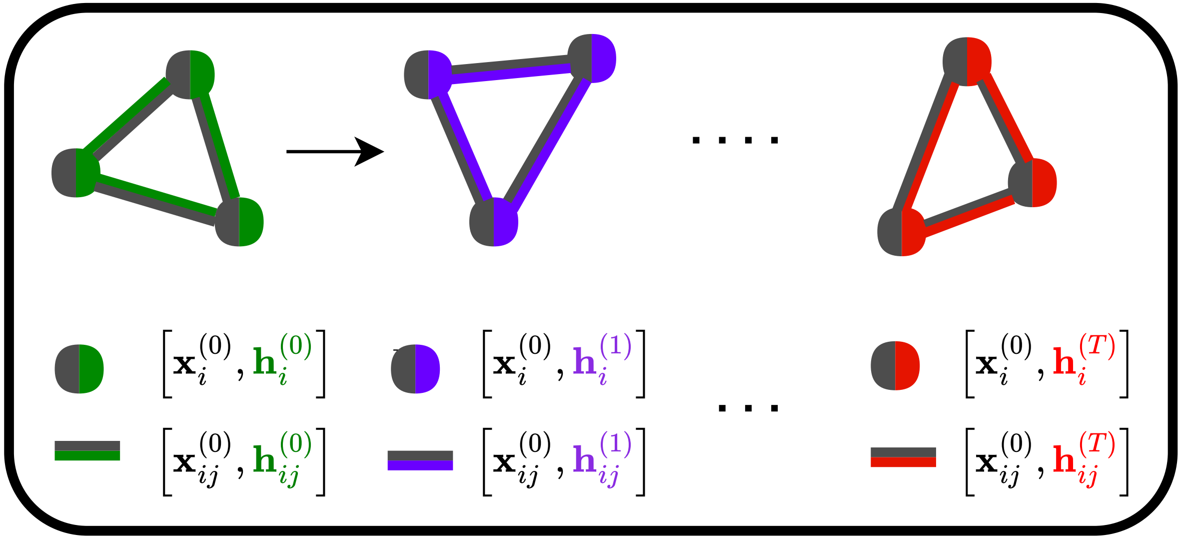
In order for the above matrix to be skew-symmetric, the neural pairing orbitals are taken to be

$$\phi(x_i, x_j) = \eta(x_i, x_j) - \eta(x_j, x_i)$$

Example: $$\text{pf}\begin{bmatrix} 0 & \phi_{12} & \phi_{13} & \phi_{14} \\ -\phi_{12} & 0 & \phi_{23} & \phi_{24} \\ -\phi_{13} & -\phi_{23} & 0 & \phi_{34} \\ -\phi_{14} & -\phi_{24} & -\phi_{34} & 0 \end{bmatrix} = \phi_{12}\phi_{34} - \phi_{13}\phi_{24} + \phi_{14}\phi_{23}$$

HOMOGENOUS ELECTRON GAS

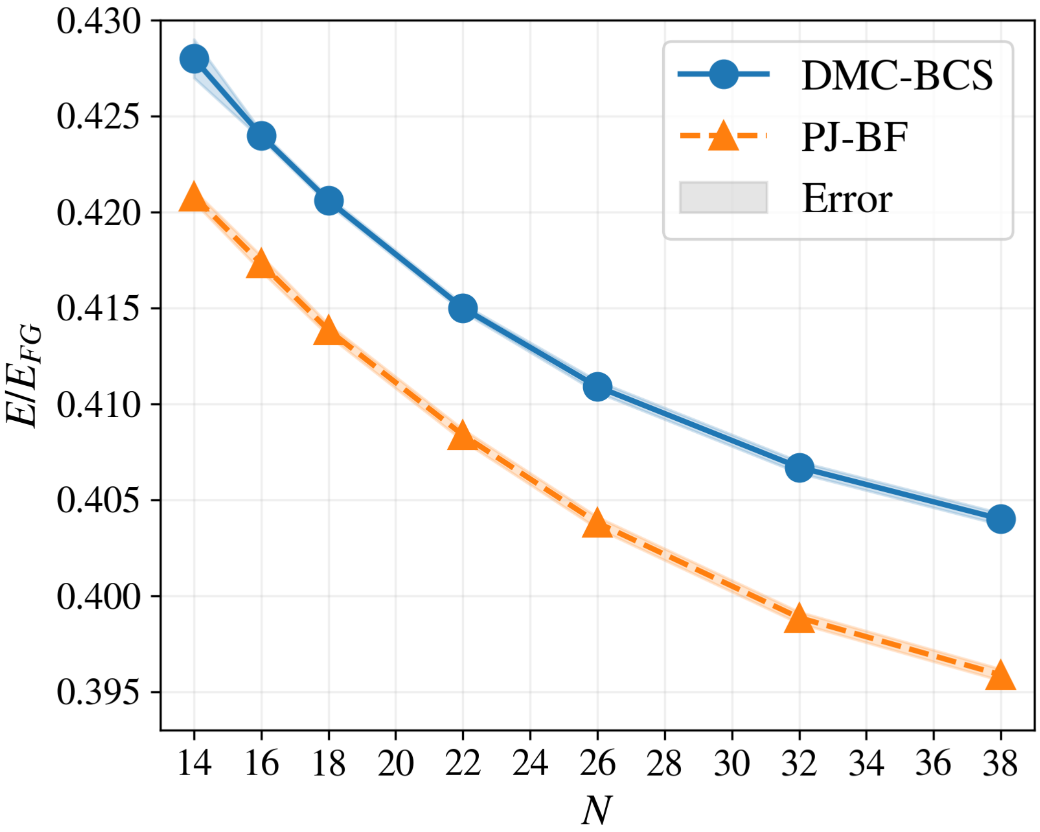
The nodal structure is improved with neural back-flow transformations $\mathbf{x}_i \rightarrow \phi(\mathbf{x}_i; \mathbf{x}_{j \neq i})$



Translation-invariant (and periodic) by construction: $\rightarrow$ $\mathbf{x}_i^{(0)} = \mathbf{e}, \quad \mathbf{x}_{ij}^{(0)} = [\mathbf{r}_{ij}, ||\mathbf{r}_{ij}||, s_i \cdot s_j].$

G. Pescia, et al., 2305.08831 [cond-mat.quant-gas]

COLD FERMI GASES



$$\left(\frac{E}{E_{FG}}\right)_{\exp} = \xi = 0.376(5)$$

J. Kim, B. Fore, AL, et al. arXiv:2305.08831

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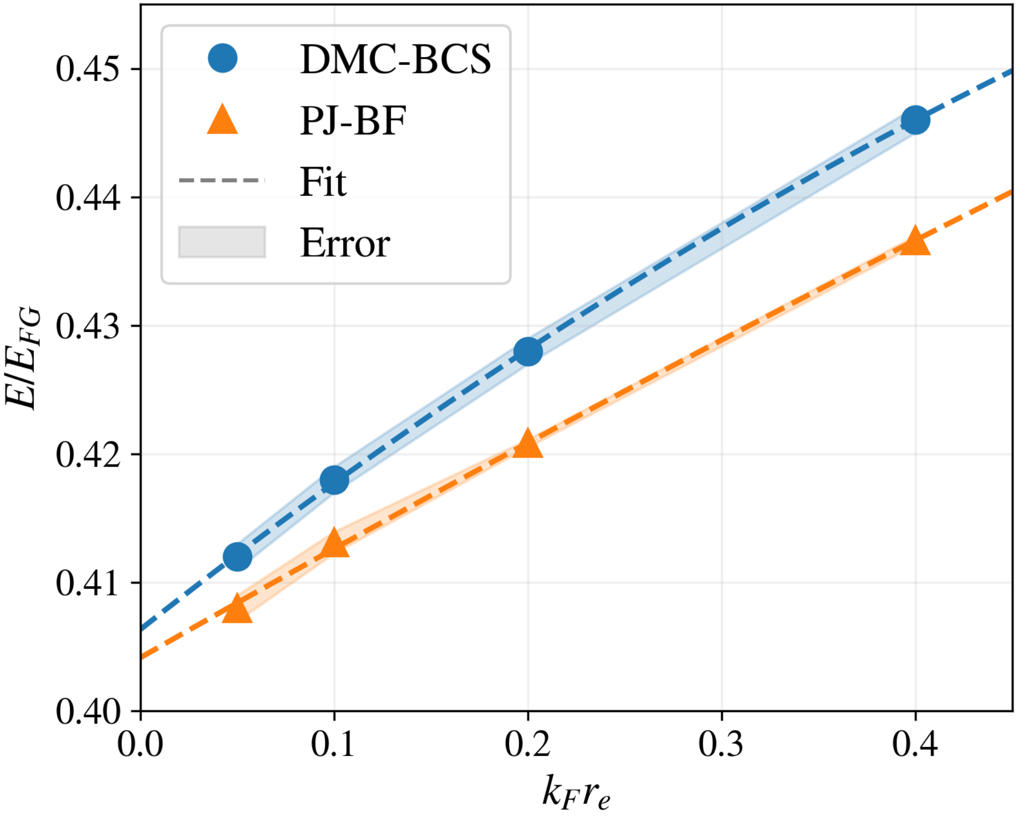
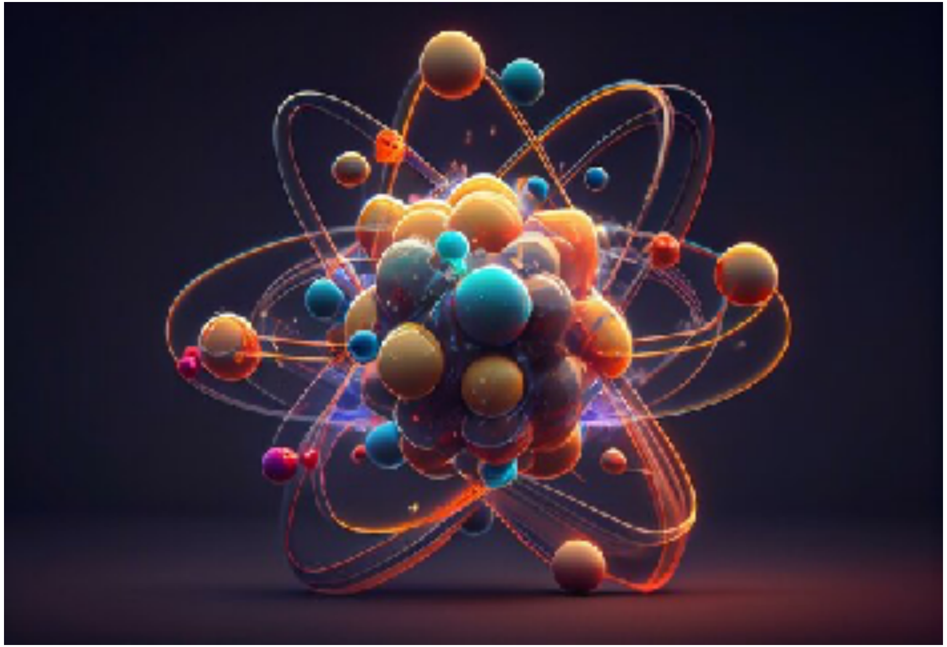


$$\left(\frac{E}{E_{FG}}\right)_{\text{exp}} = \xi = 0.376(5)$$

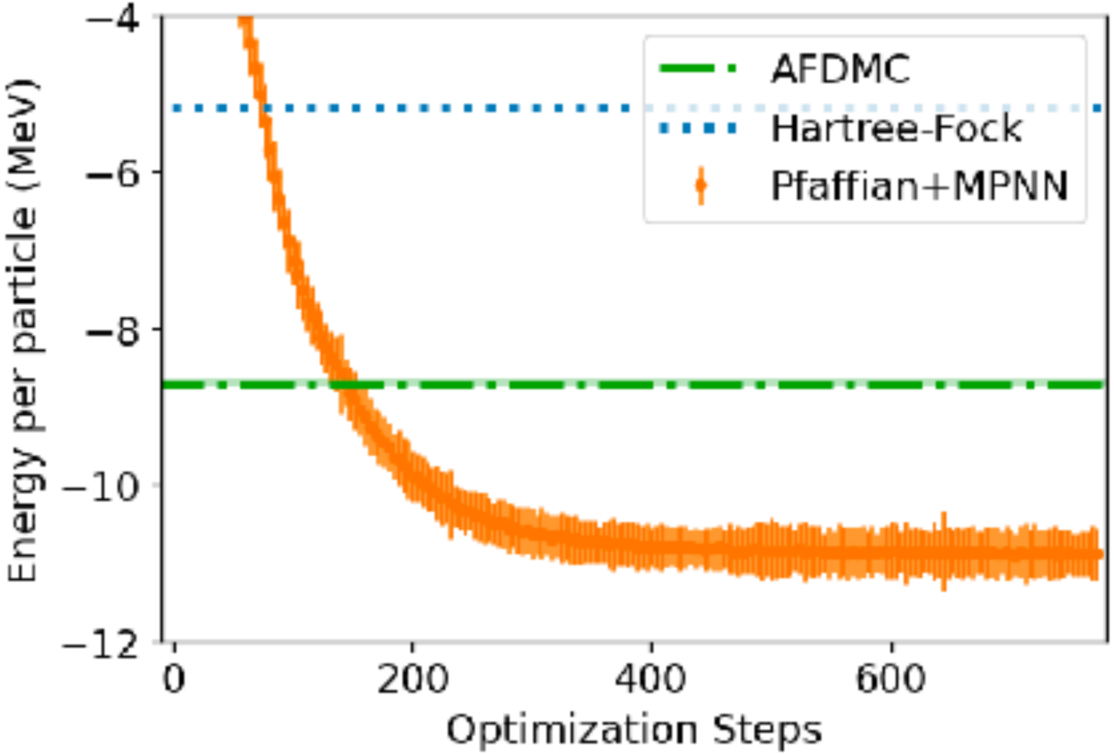
J. Kim, B. Fore, AL, et al. arXiv:2305.08831

BACK TO NUCLEAR PHYSICS



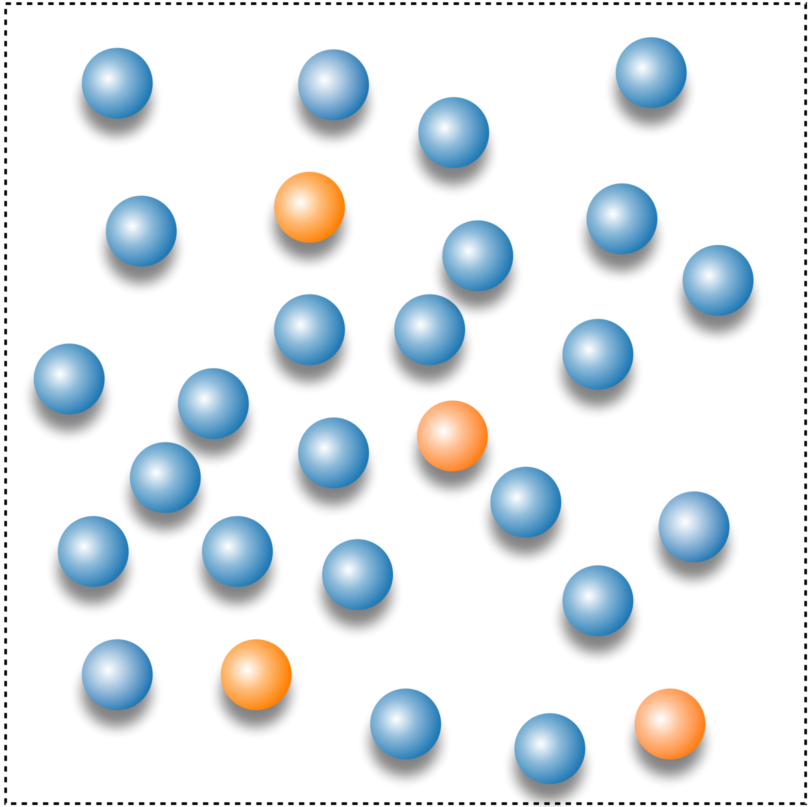
DILUTE NUCLEONIC MATTER WITH MPNN

14 Neutrons, 14 Protons @ ρ=0.04 fm^{-3}



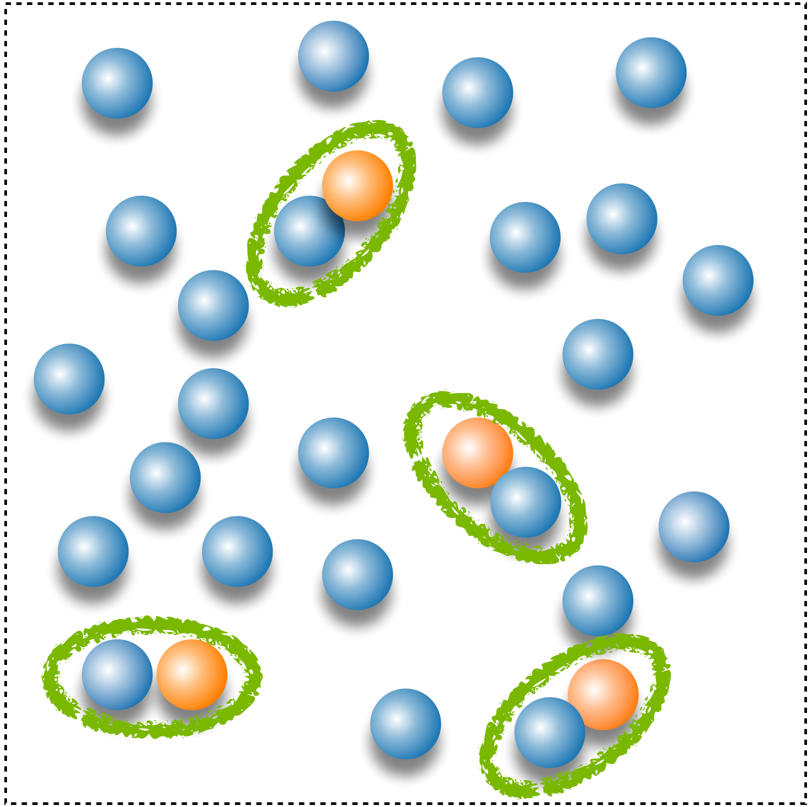
DILUTE NUCLEONIC MATTER WITH MPNN

Liquid phase



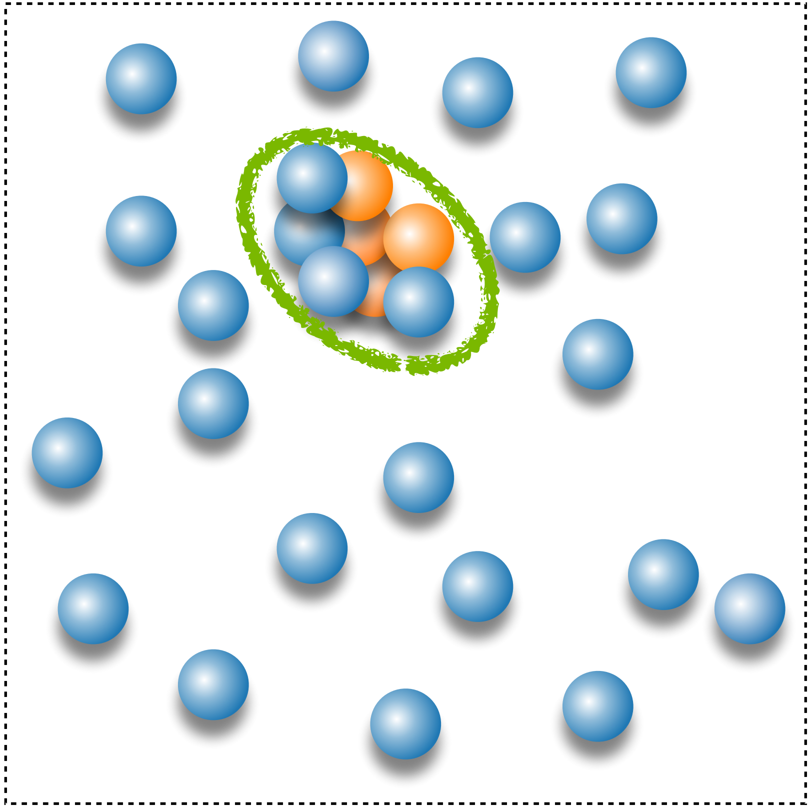
DILUTE NUCLEONIC MATTER WITH MPNN

^{2}H clusters



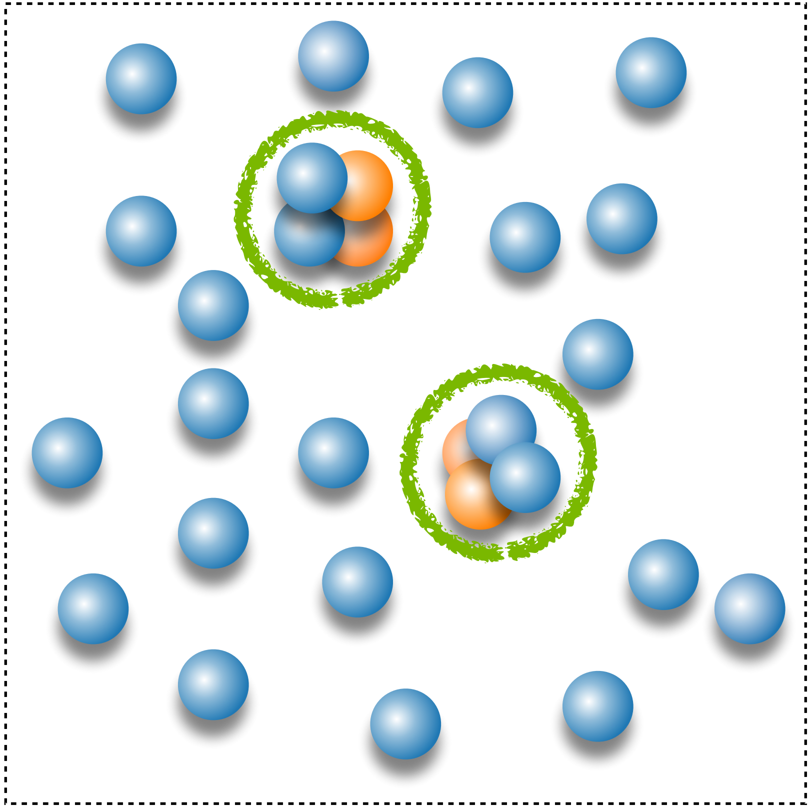
DILUTE NUCLEONIC MATTER WITH MPNN

^{8}Be clusters



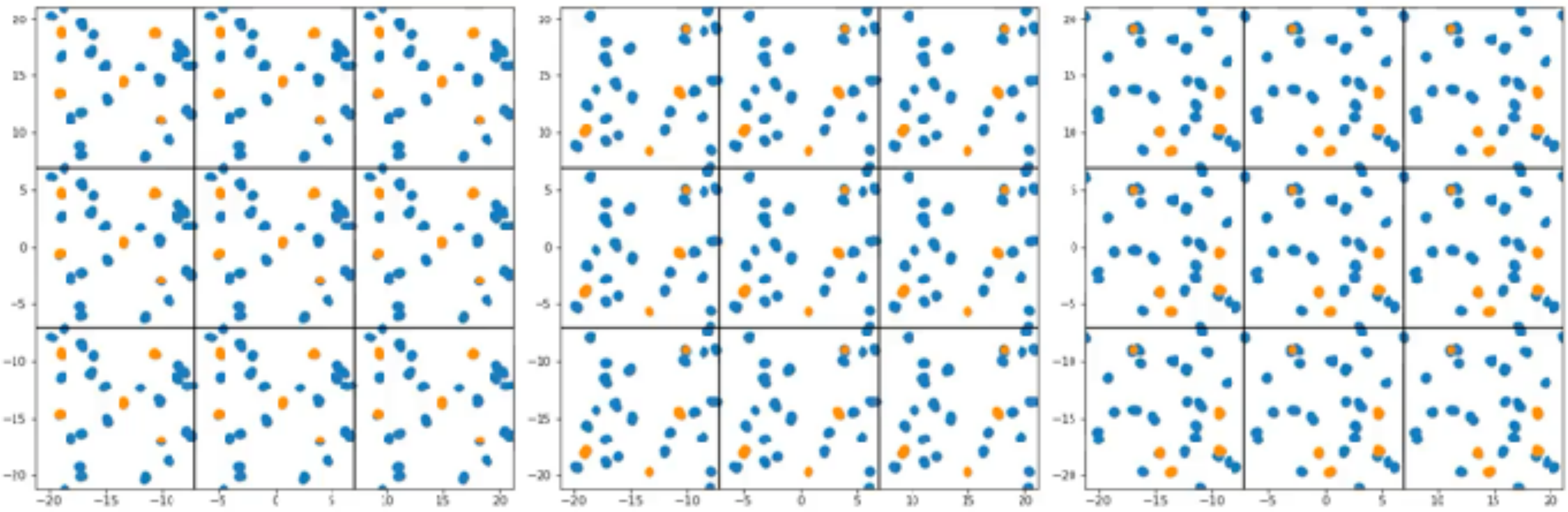
DILUTE NUCLEONIC MATTER WITH MPNN

^{4}He clusters



DILUTE NUCLEONIC MATTER WITH MPNN

24 Neutrons, 4 Protons @ ρ=0.01 fm^{-3}



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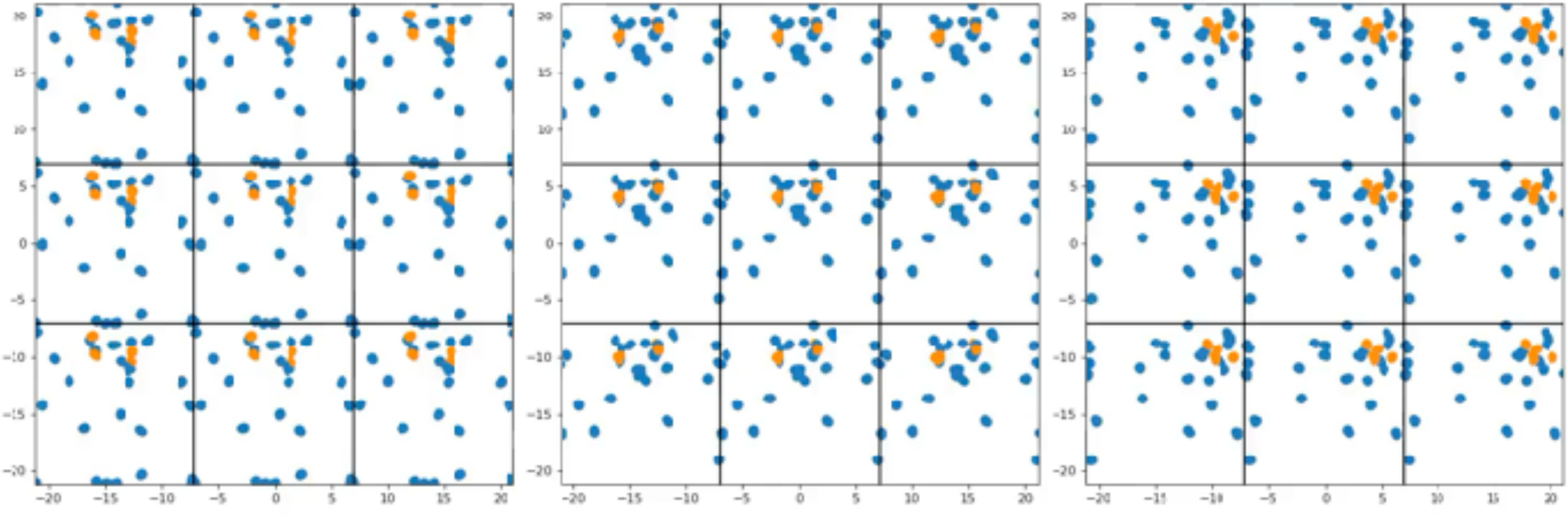

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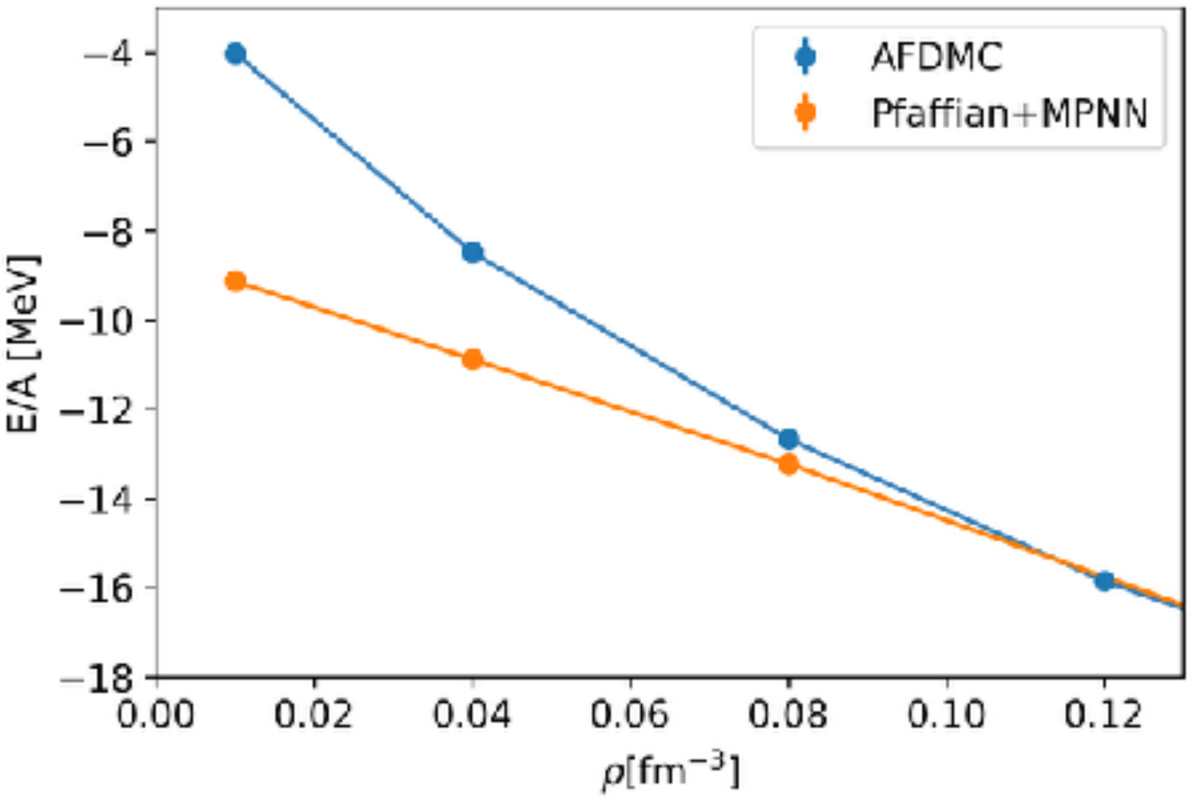

ESSENTIAL ELEMENTS OF NUCLEAR BINDING

Physics Letters B 797 (2019) 134863

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Essential elements for nuclear binding

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[b] Helmholtz-Institut für Strahlen- und Kernphysik and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany
[c] Faculty of Engineering, Karamanoglu Mehmetbey University, Karaman 70100, Turkey
[d] Ruhr-University Bochum, Faculty of Physics and Astronomy, Institute for Theoretical Physics II, D-44870 Bochum, Germany
[e] Institute for Advanced Simulation, Institut für Kernphysik, and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany
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PHYSICAL REVIEW C 103, 054003 (2021)

Two- and three-nucleon contact interactions and ground-state energies of light- and medium-mass nuclei

R. Schiavilla,[1,2] L. Girlanda,[3,4] A. Gnech,[2,5] A. Kievsky,[6] A. Lovato,[7,8] L. E. Marcucci,[5,6] M. Piarulli,[9] and M. Viviani[5]

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[9] Department of Physics, Washington University in St. Louis, St. Louis, Missouri 63130, USA

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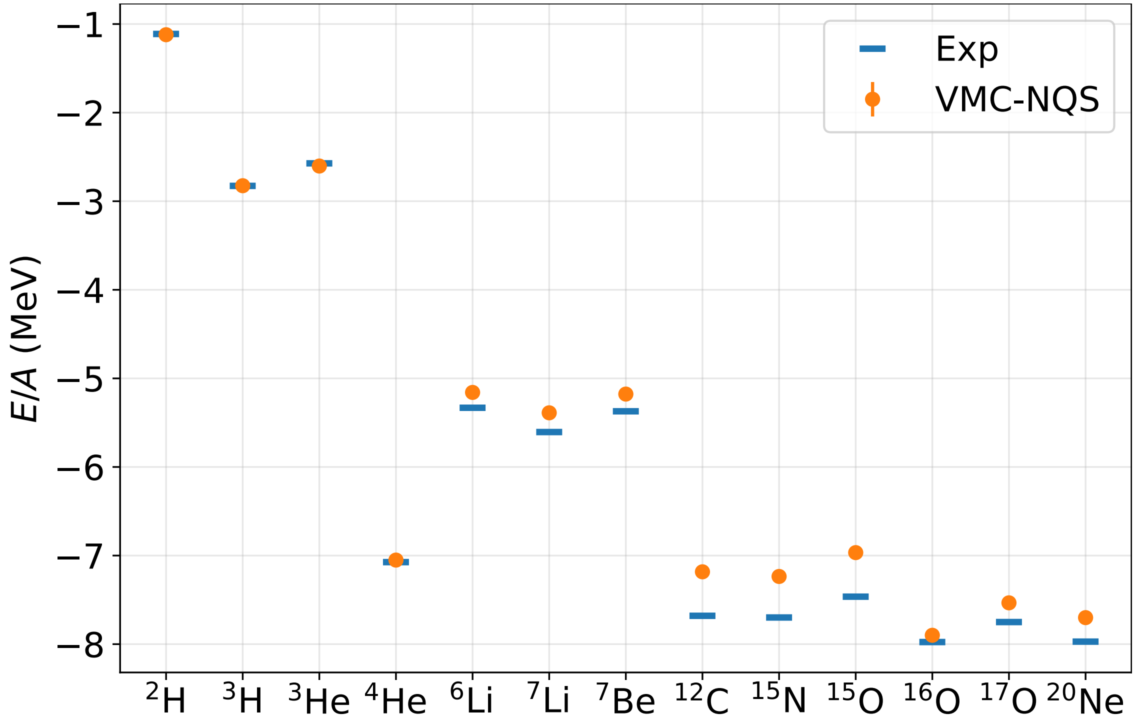
ESSENTIAL ELEMENTS OF NUCLEAR BINDING

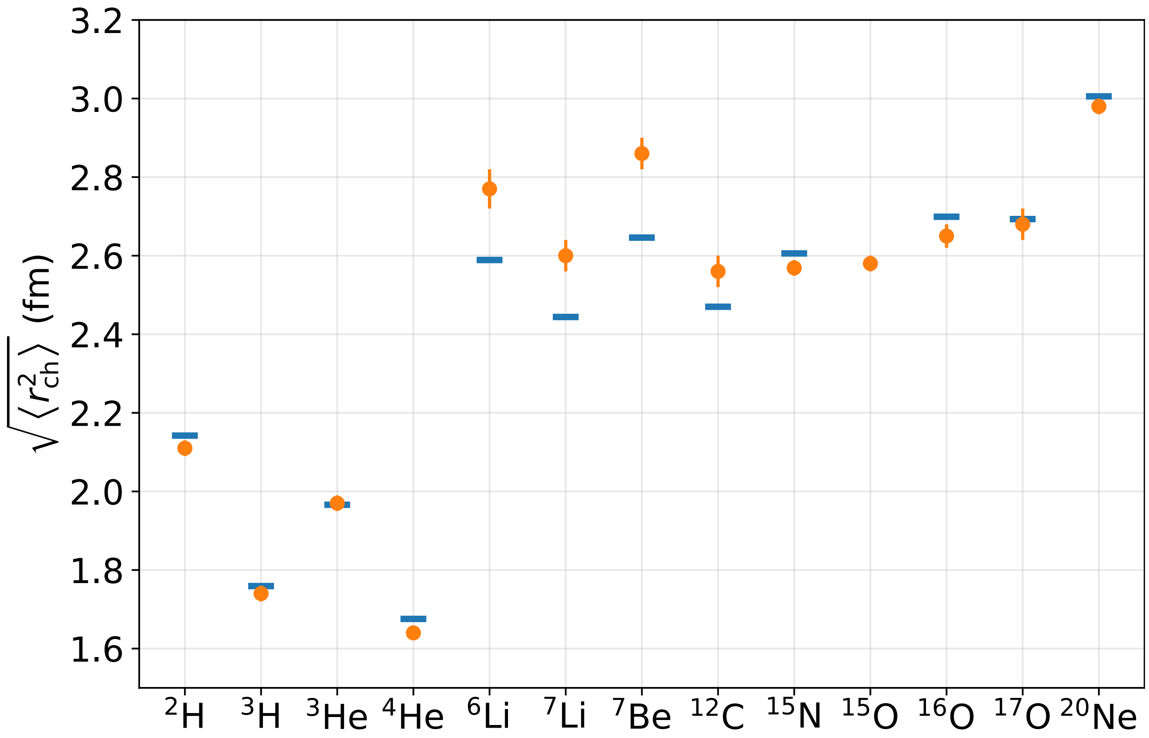
A simple pionless-EFT Hamiltonian reproduces well the spectrum of different nuclei



A. Gnech, et al., 2308.16266

ESSENTIAL ELEMENTS OF NUCLEAR BINDING

Deviations from experiments are more pronounced for charge radii

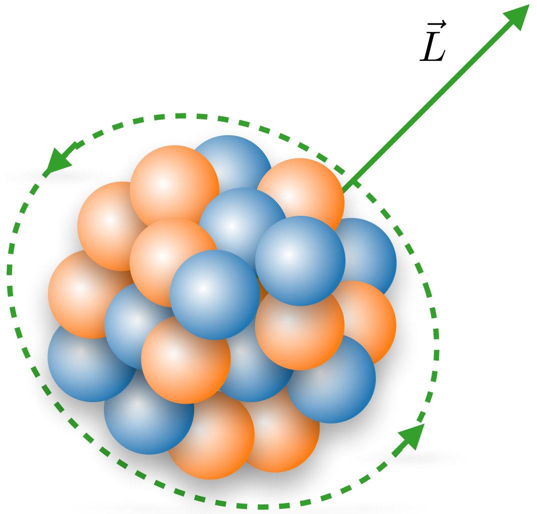


A. Gnech, et al., 2308.16266

MAGNETIC MOMENTS

The ground-state is generate in L_z

$$|\Psi_{HN}; L, S\rangle = \sum_{L_z S_z} c^{L,S}_{L_z S_z} |L, L_z; S, S_z\rangle.$$



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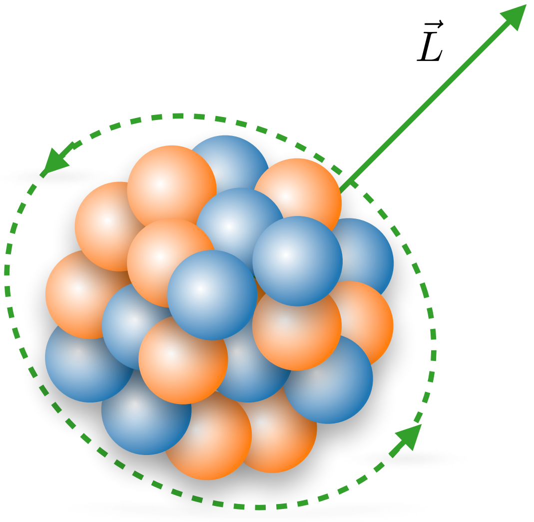
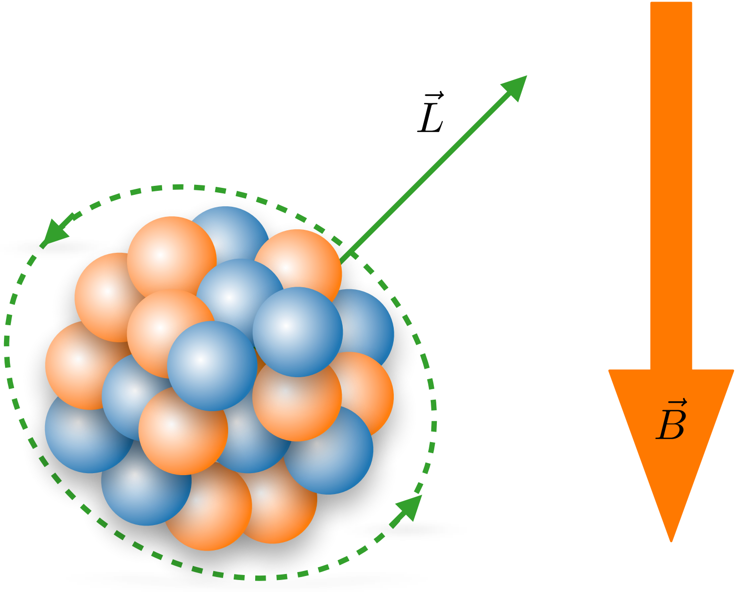


Remove this degeneracy by

$$H \to H - B_z L_z$$



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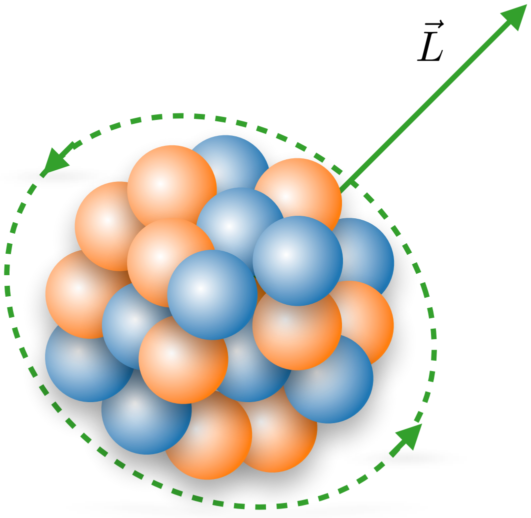

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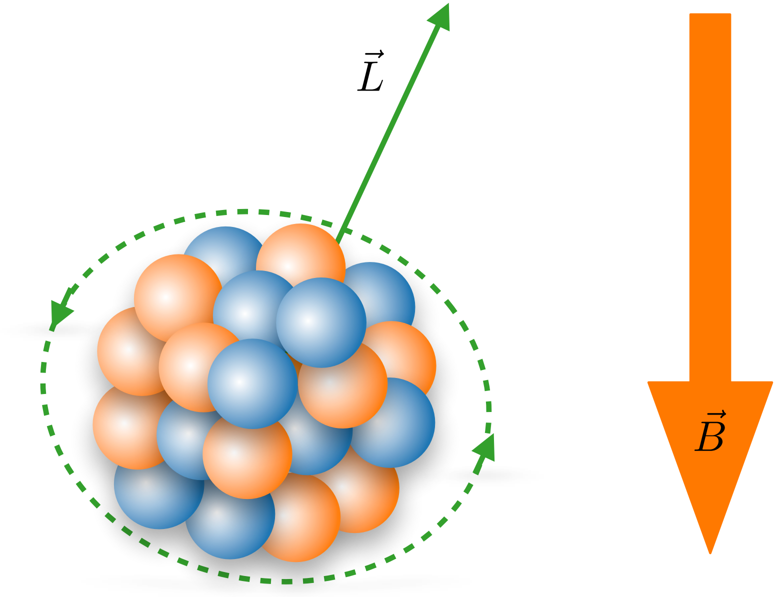

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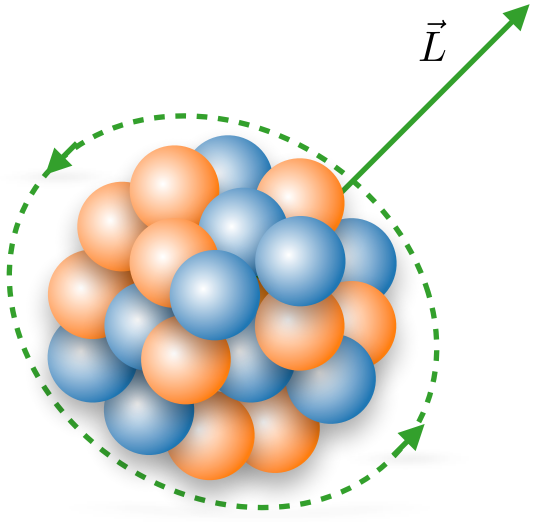
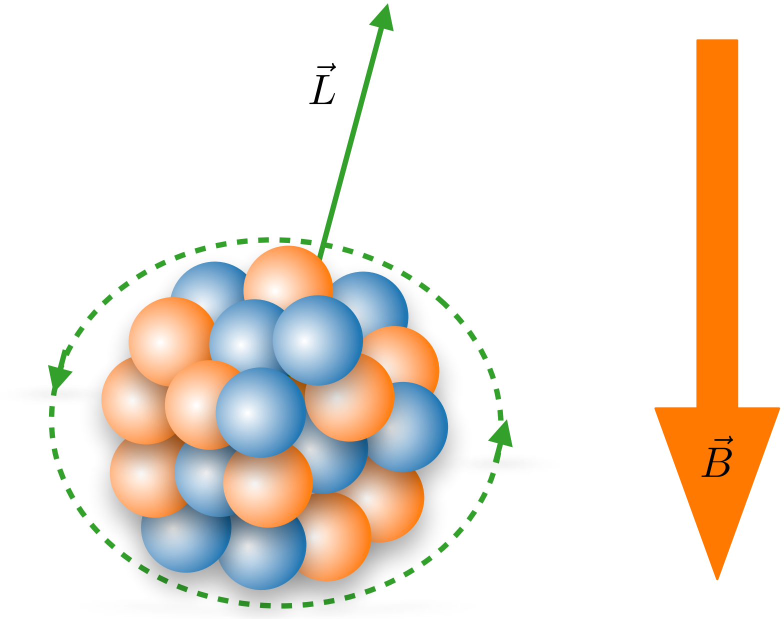


Remove this degeneracy by

$$H \rightarrow H - B_z L_z$$



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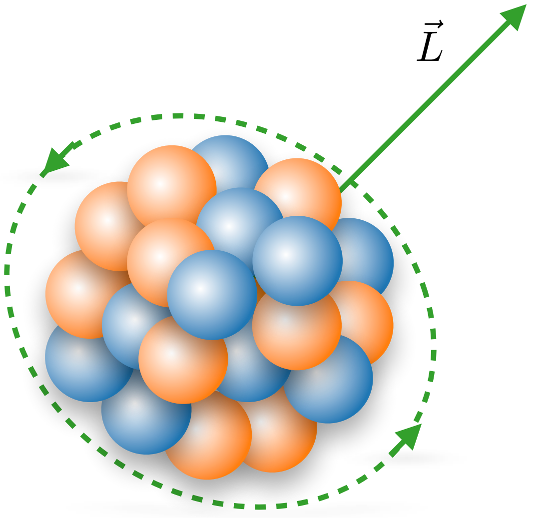

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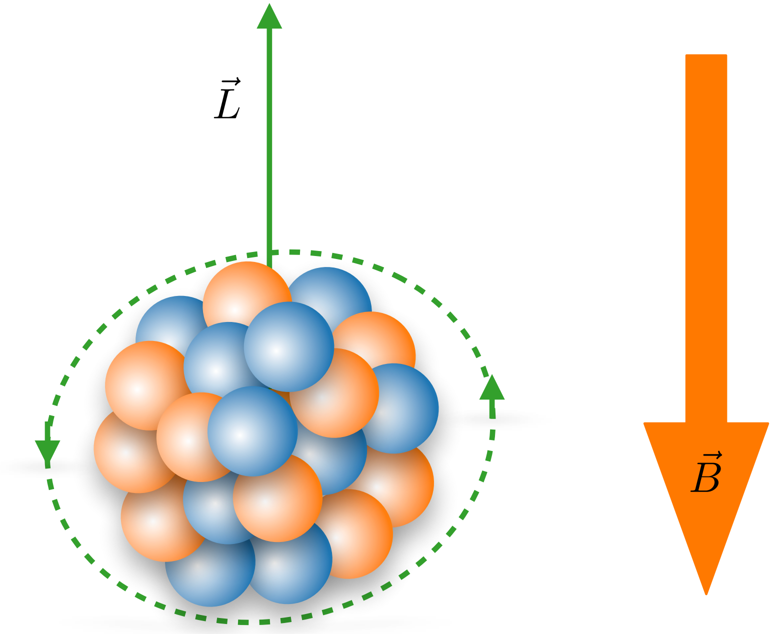
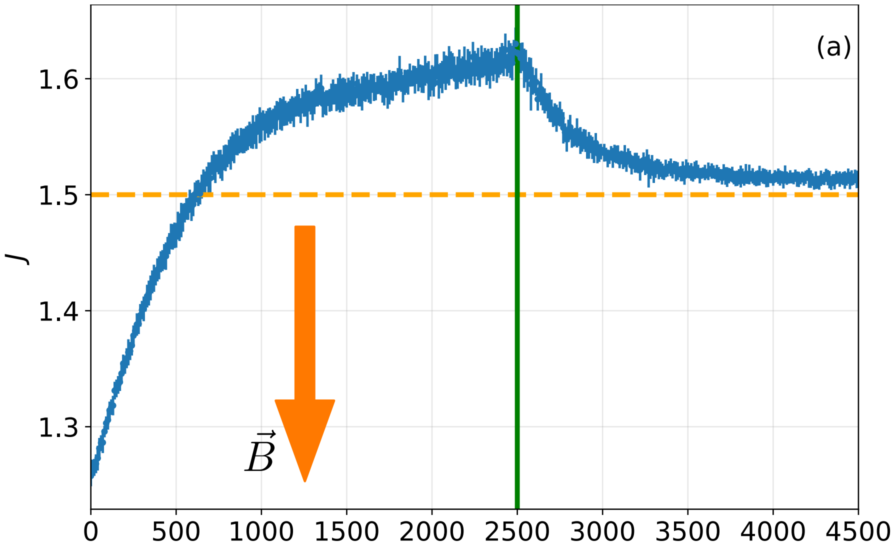
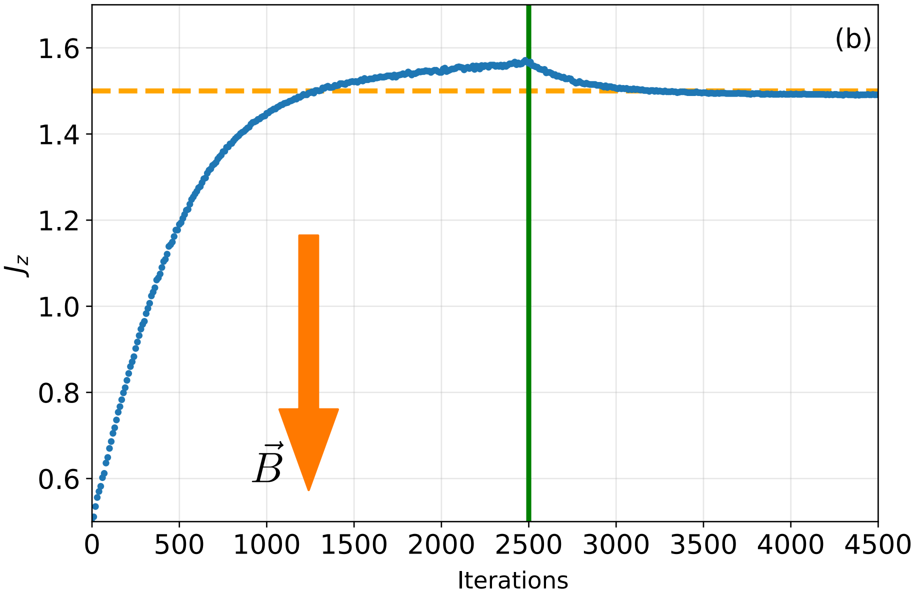


MAGNETIC MOMENTS





A. Gnech, et al., 2308.16266

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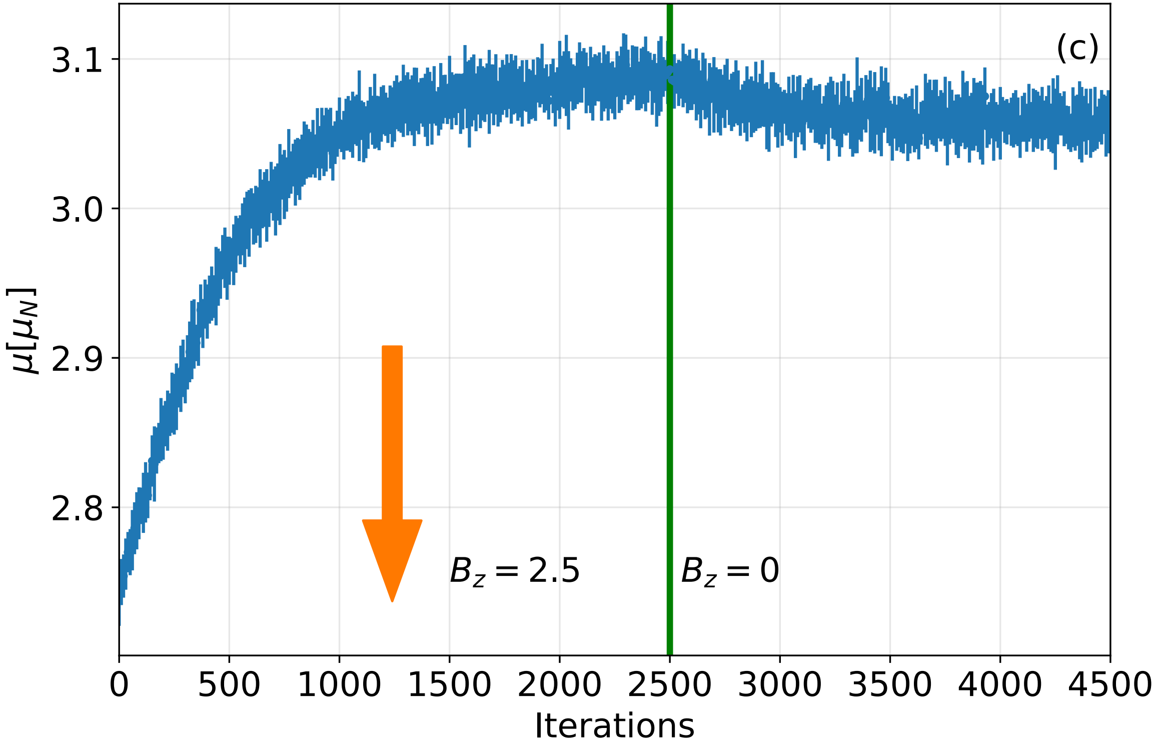
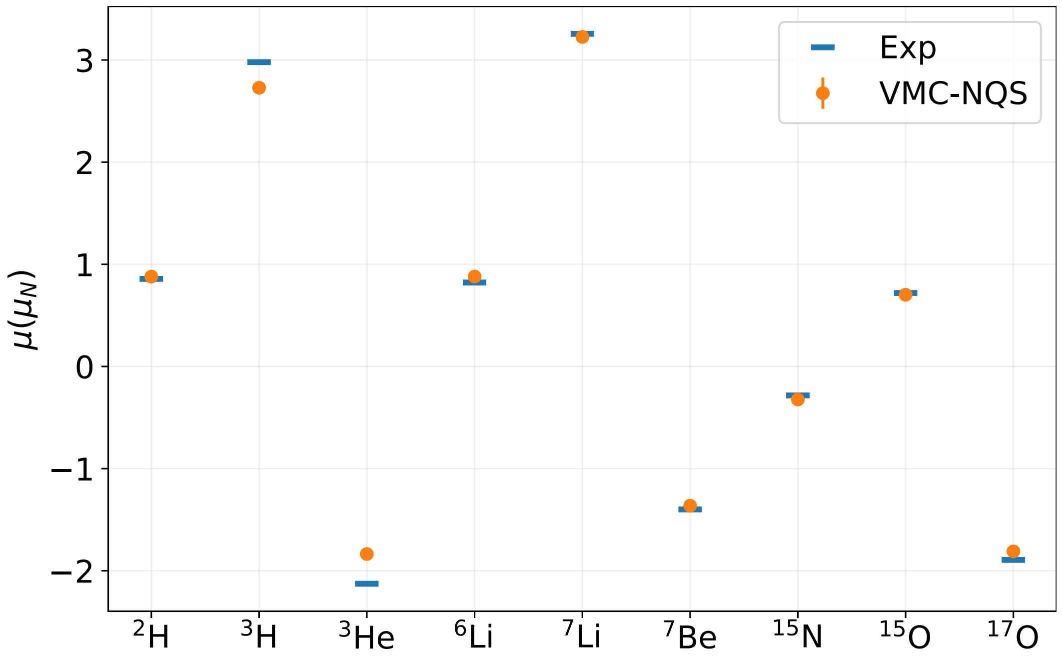


A. Gnech, et al., 2308.16266

MAGNETIC MOMENTS WITH MPNN

In addition to energies and single-particle densities, we compute electroweak properties



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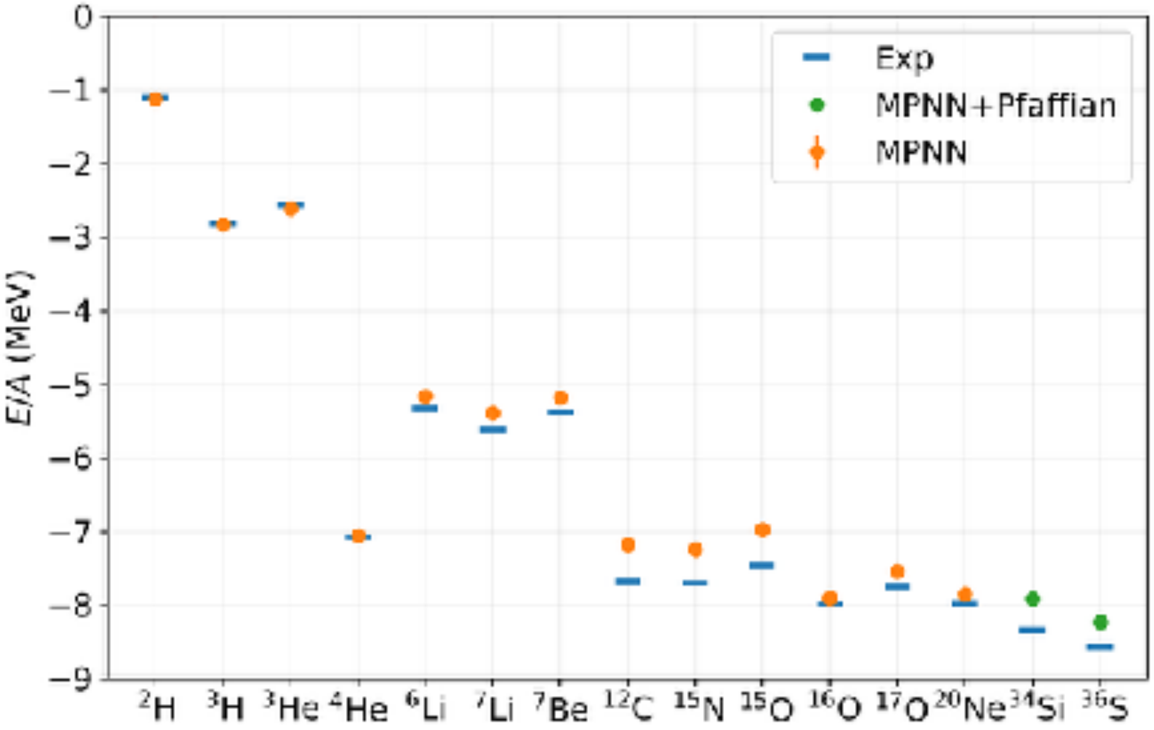
ESSENTIAL ELEMENTS OF NUCLEAR BINDING

A simple pionless-EFT Hamiltonian reproduces well the spectrum of different nuclei



HIGH-PERFORMANCE COMPUTING

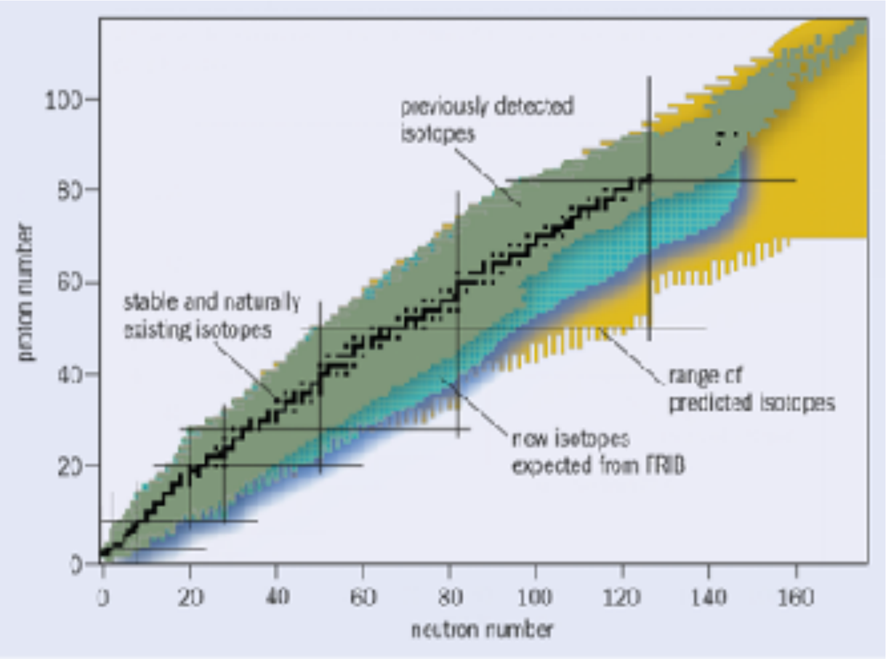
The variational Monte Carlo with neural network quantum state code is by design scalable to leadership-class hybrid CPU/GPU computers

PERSPECTIVES

- **Larger nuclei** are within reach on leadership-class machines

➡ Optimized version of the code reaches ^{76}Ge on Polaris @ANL

➡ Work in progress to port it to Intel Ponte Vecchio (^{100}Sn and beyond on Aurora @ANL)



PERSPECTIVES

- **Real-time dynamics** is the prototypal exponentially-hard problem in many-body theory

  ➡ Relevant for: fission, fusion lepton- and hadron-nucleus scattering

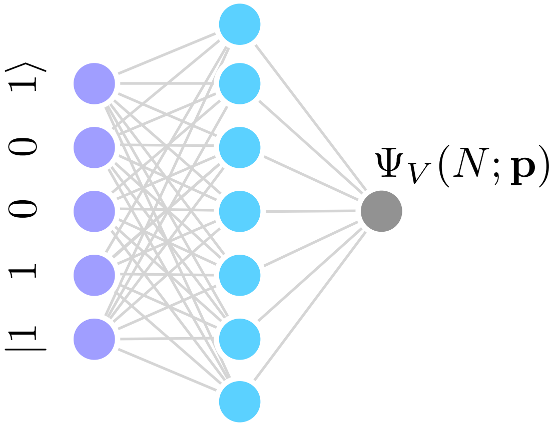
  ➡ Learn from TDHF calculations: collaboration with K. Godbey, W. Nazarewicz, and N. Rocco.

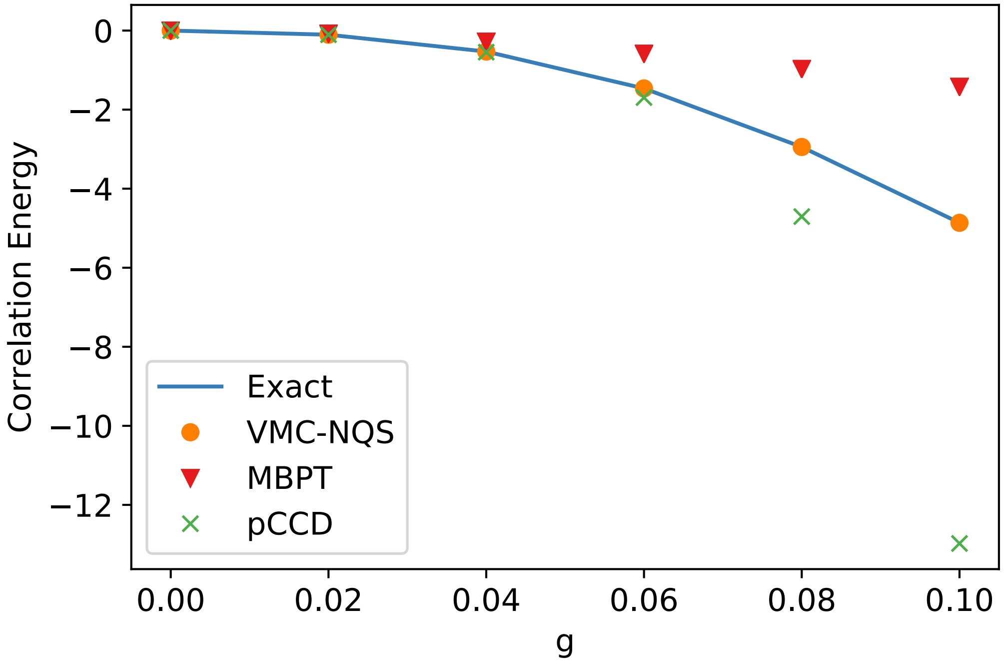
$$\mathcal{D}\left(|\Psi(\mathbf{p}_{t+\delta t})\rangle, e^{-iHt}|\Psi(\mathbf{p}_t)\right)^2 = \arccos\left(\sqrt{\frac{\langle\Psi(\mathbf{p}_{t+\delta t})|e^{-iHt}|\Psi(\mathbf{p}_t)\rangle\langle\Psi(\mathbf{p}_t)|e^{iHt}|\Psi(\mathbf{p}_{t+\delta t})\rangle}{\langle\Psi(\mathbf{p}_{t+\delta t})|\Psi(\mathbf{p}_{t+\delta t})\rangle\langle\Psi(\mathbf{p}_t)|\Psi(\mathbf{p}_{\tau+\delta t})\rangle}}\right)^2$$

  ➡ Alternative approach based on integral transform, with N. Barnea, E. Parnes, and N. Rocco

SOME PERSPECTIVES:

- **Occupation number formalism** allows to naturally satisfy Pauli's exclusion principle





THANK YOU