Simulating nuclei with digital quantum computers

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The nuclear shell model is one of the prime many-body methods to study the structure of atomic nuclei, but it is hampered by an exponential scaling on the basis size as the number of particles increases. We present a shell-model quantum circuit design strategy to find nuclear ground states that circumvents this limitation by exploiting an adaptive variational quantum eigensolver algorithm. Our circuit implementation is in excellent agreement with classical shell-model simulations for a dozen of light and medium-mass nuclei, including neon and calcium isotopes. We quantify the circuit depth, width and number of gates to encode realistic shell-model wavefunctions. Our strategy also addresses explicitly energy measurements and the required number of circuits to perform them. Our simulated circuits approach the benchmark results exponentially with a polynomial scaling in quantum resources for each nucleus and configuration space. This work paves the way for quantum computing shell-model studies across the nuclear chart.

References

[1] A. Pérez-Obiol, A.M. Romero, J. Menéndez, A. Ríos, A. García-Sáez, B. Juliá-Díaz, arXiv:2302.03641 (2023)

[2] A. M. Romero, J. Engel, Ho Lun Tang, Sophia E. Economou, Physical Review C, 105(6), 064317 (2022)

Figures

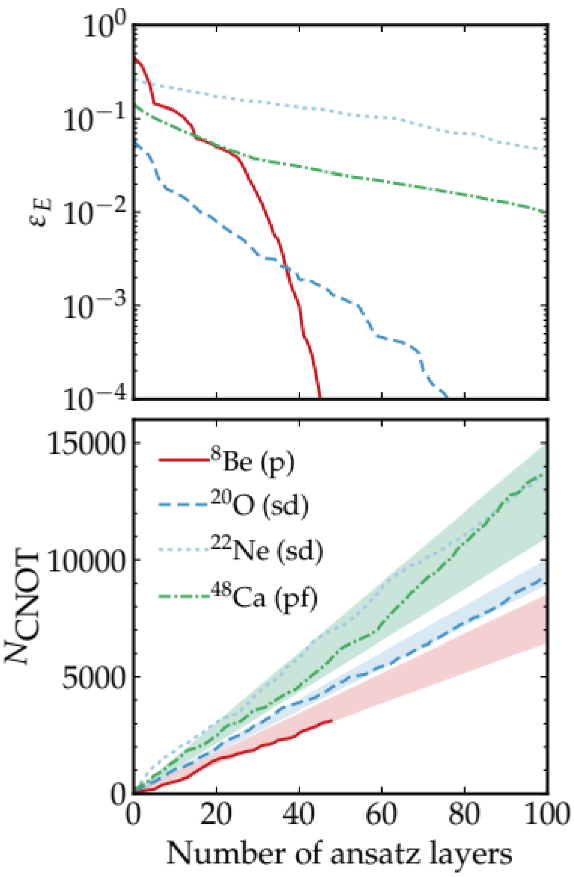

Figure 1: Evolution of the relative error for the ground-state energy (top) and number of CNOT gates in the ansatz circuit (bottom) as a function of the number of ansatz layers for simulations of selected nuclei. As the algorithm adaptively iterates, errors decay exponentially while the number of CNOT gates increases linearly.