PROPOSAL FOR A PHD PROJECT

Implementation of nuclear and many-body problems on Rydberg atoms quantum computers

DESCRIPTION OF THE SUBJECT

Recent developments in quantum computing open opportunities to explore alternative methods for tackling complex problems that could not be solved using classical computers. An accurate solution of nuclear physics many-body problems typically requires sophisticated numerical codes and considerable computational resources. In this context, the proposed PhD thesis aims to explore the use of Rydberg atoms quantum processors for the description of many-fermion systems, with a focus on nuclear physics.

On the one hand, quantum computing algorithms tailored to treat fermions interacting with each other are being developed [1]. While implementing such algorithms on quantum emulators is becoming standard, testing their effectiveness on real quantum machines remains an open issue.

On the other hand, quantum processing units (QPUs) based on manipulating neutral atoms have been put forward as one of the most promising technologies for quantum simulations [2]. Such machines are now becoming available for fundamental research applications, thus offering the opportunity to perform real calculations and gauge the perspectives of so-called Noisy Intermediate Scale Quantum (NISQ) technology.

This project aims to combine these state-of-the-art developments with the following goals:

(a) Implement existing or new quantum algorithms on the neutral atoms QPUs, exploring the different possibilities offered by the machine and respecting/exploiting the specificities of nuclear systems (e.g., the use of symmetry breaking and restoration, understanding entanglement and phase-transition in the description of many-body states [3]).

(b) Demonstrate the usefulness of the Rydberg atoms quantum processor for solving real-world many-body physics problems. This will involve selecting a set of pilot applications that represent typical problems in the field and applying the developed algorithms to solve them. The student will need to compare the results obtained using the quantum computer with those obtained using traditional approaches to validate the effectiveness of the proposed methods.

[1] T. Ayral *et al.*, arXiv :2303.04850 (2023).

[2] L. Henriet *et al.*, Quantum 4, 327 (2020).

[3] D. Lacroix *et al*, Eur. Phys. J. A 59:3 (2023).

GROUP/LAB/ADVISOR

The project will be part of a collaboration between the "Laboratoire de Physique des deux infinis Irène Joliot-Curie" (IJCLab) in Orsay, and the Department of Nuclear Physics (DPhN) of the CEA Saclay. The student will be co-supervised by by Denis Lacroix (IJCLab), and by Vittorio Somà (DPhN), and is expected to share the time between the two labs.

WORK PLAN

The following plan can be envisaged for the project

(i) ***Training on Rydberg atoms QPUs***: learn the specificities of the physical QPUs and their constraints for applications.

(ii) ***Hamiltonian encoding***: given the above constraints, study different encoding strategies for Hamiltonians relevant for nuclear and many-body physics.

(iii) ***Applications on emulators and real quantum devices:*** test different techniques (e.g., variational or propagator, with or without symmetry breaking/restoration) for many-body problems, with a focus on nuclear physics calculations on the QPUs.

REQUIRED SKILLS

The candidate must have a master's diploma in physics, mathematics, or computer science. A strong education in theoretical physics (especially quantum mechanics) and competency in scientific computing are preferable.

ACQUIRED SKILLS

The student will develop strong competencies in quantum computing, many-body theory, and low-energy nuclear physics. He/she will get acquainted with teamwork, develop outreach skills and learn to take initiative in a collaborative effort.

COLLABORATIONS

The project will be conducted within the context of the France Hybrid HPC Quantum Initiative (HQI), which favors collaborations with other students and groups carrying out research activities in quantum computing, particularly for applications to many-body systems (e.g., in quantum chemistry or condensed matter).

CONTACTS

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