Dottorato di Ricerca in Fisica – PhD in Physics
(XLII Ciclo)

Research Project:

Title:
Error-resilient quantum information processing with neutral atom qudits

Abstract:
Neutral atoms (NAs) are a leading platform for quantum information processing, providing exceptional scalability, long coherence times, and precise control by optical/radio-frequency pulses. NAs quantum simulators are already close to solve open problems in material science [1], but the implementation of a scalable architecture supporting quantum error correction is still far. This limitation can be overcome by exploiting the intrinsic multi-level structure of NAs to encode information into multi-level units (qudits) and embed quantum error correction within individual objects, thus greatly simplifying its implementation [2].
The PhD thesis will focus on the design and numerical simulation of schemes for (i) quantum simulation of Fermi- and Bose-Hubbard models exploiting NA qudits for efficient encoding and error correction; (ii) quantum machine learning (QML) [3], leveraging NA qudits to enable a significant reduction in circuit depth and gate count, thus alleviating the fundamental issue of barren plateau and projecting QML to transcend computational boundaries of classical paradigms.

The implementation of a quantum simulator with embedded quantum error correction and of noise-resilient QML protocols (with potential exponential speedups, e.g. in high-dimensional pattern recognition) would represent a breakthrough towards the demonstration of quantum advantage.
Algorithms developed for NA qudits will impact the whole interdisciplinary community working on quantum computing, simulation, sensing and communication. The focus on NAs will put the PhD student in contact with the strong experimental Italian Research community working in the field.

[1] M. Xu et al., Nature **642**, 909 (2025)
[2] A. Chiesa et al., Rep. Progr. Phys. **87**, 034501 (2024)
[3] Y. Wang et al., Rep. Prog. Phys. **87** 116402 (2024)

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