Quantum computing and scientific research: state of the art and potential impact in nuclear physics

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I. SCIENTIFIC ISSUE

Few decades after the seminal work of Richard Feynman, early practical implementations of quantum computing devices are being realised. On the one hand, the enormous challenges to viably increase the number of quantum bits (qubits) in prototype machines entertain large uncertainties on the timescale of advantageous applications. On the other hand, the ongoing progress in quantum algorithms (i.e. algorithms that need to be specifically designed for solving a problem by means of a quantum simulation) suggests a huge potential impact in scientific research. Both are attracting increasing resources, with all IT colossi heavily investing on the former, i.e. on quantum hardware, and quantum information theorists/developers on the latter, i.e. quantum software.

The acceleration of quantum computing technology coincides with the increased awareness that conventional computational resources will face the physical limits of their basic components (e.g. silicon transistors and circuits) in a foreseeable future. Indeed, if the current horizon of high-performance computing is represented by exascale machines, further perspectives are much more uncertain and are confronted with the predicted breakdown of "Moore's law". In this context, the development of quantum technologies is appealing for all fields of research that crucially rely on computational capabilities. In particular, the ab initio description of atomic nuclei or molecules has made tremendous progress in the last twenty years to extend its reach towards heavier and/or open-shell fermionic systems. Still, the quantum many-body problem faces computational challenges to further extends its scope and could thus benefit from the very favourable scaling of quantum simulations on the number of physical constituents, potentially tackling problems that currently are (and would be for a long time) out of reach for conventional computations.

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Although appropriate algorithms for the emerging quantum architectures are being developed, the set of problems and applications for which they are optimised remain limited. In this regard, an interesting interplay could occur between the design of quantum algorithms to be applied in nuclear physics and quantum many-body formalisms developed in recent years (or to be yet developed).

II. GOALS

The main goals of the workshop are:

1. To inform/educate the local research community on the state of the art and near-future perspectives in quantum computing
2. To examine the fields of scientific research where quantum simulations are expected to lead to important breakthroughs
3. To review the progress in quantum algorithms and explore the potential interplay with quantum many-body formalisms
4. To discuss potential impact of quantum simulations on nuclear physics research

III. PROGRAM

Structure

The meeting takes place over three days. The first day is devoted to introductory/pedagogical presentations that have the aim of informing/educating the local research community on the founding principles, the state-of-the-art and the perspectives of quantum computing. The second and third days will be more focused on the potential impact of quantum simulations on nuclear physics research, with discussion on prospective applications, progress in quantum algorithms and their connection to the nuclear many-body problem.

Speakers and topics

Introductory lecture

- Anthony Leverrier (INRIA, France)
  Part I: Basic quantum mechanical principles of quantum computing
  Part II: Theory of quantum algorithms

Talks

- Thomas Ayral (Atos, France)
  Quantum emulators and scientific research
- Guillaume Colin de Verdière (CEA DAM, France)
  Teratec Quantum Computing Initiative
- Pierre-Luc Dallaire-Demers (Xanadu, Toronto, Canada)
  Preparing correlated fermionic states on a quantum computer
- Jens Eisert (Freie Universität Berlin, Germany)
  Quantum advantages of quantum simulators probing strongly correlated systems and of near-term quantum computers
- Daniel Estève (CEA Saclay, France)
  How do we fabricate a quantum bit?
- Alexei Grinbaum (CEA Saclay, France)
  Quantum foundations in the XXI century

- Gaute Hagen (Oak Ridge National Lab, USA)
  First quantum computation of an atomic nucleus
- Thomas O'Brien (Leiden University, The Netherlands)
  Quantum algorithms for strongly-correlated chemistry and physics problems
- Alessandro Roggero (INT Seattle, USA)
  Nuclear dynamics with quantum computers
- Alexander Tichai (CEA Saclay, France)
  Nuclear many-body formalisms and computation
- Jacob Watkins (Michigan State University, USA)
  Nuclear physics and quantum computing

Schedule

Wednesday 12/6		Thursday 13/6		Friday 14/6	
9:15	Welcome	9:15	**Eisert**	9:15	**Dallaire-Demers**
9:30	**Leverrier I**	10:15	Break	10:15	Break
11:00	Break	10:45	**Tichai**	10:45	**Roggero**
11:30	**Leverrier II**	11:45	**Hagen**	11:45	**Colin de Verdière**
13:00	Lunch	12:45	Lunch	12:45	Lunch
14:15	**Grinbaum**	14:00	**Ayral**	14:00	**Watkins**
15:15	Break	15:00	Break	15:00	Break
15:45	**Estève**	15:30	**O'Brien**	15:30	*Discussions*
16:45	*Discussions*	16:30	*Discussions*	16:30	End
17:45	End	17:30	End		
		20:00	Social dinner		