MITP topical workshop

Quantum Methods for Lattice Gauge Theories Calculations

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Overview

The workshop brought together the expertise of scientists on high-energy-physics, lattice calculations and scientists exploring the route toward quantum lattice calculations, aiming to bridge the different communities, with the goal of reporting the current status of research, indicate possible critical aspects, and unveil new ideas and approaches based on decades of experience in lattice calculations. Two different dimensions have been explored:

The development of theoretical and numerical quantum information tools to study Lattice Gauge Theories (LGTs): sophisticated numerical simulations performed on classical computers mainly based on – but not limited to – matrix product states and tensor networks, which were originally developed in the context of quantum information science and have arisen as promising alternative numerical tools to address challenging questions in strongly correlated condensed matter and in LGTs.

The development of the theoretical tools to design, develop and verify quantum simulations of LGTs and the implementation of experimental proof of principle quantum simulations of LGTs. While it is currently unclear which combination of theoretical approach (Wilson's LGT or quantum link models), numerical method (hybrid Monte Carlo, cluster algorithms), and experimental quantum technology (ultracold atoms, trapped ions, or superconducting circuits) is best suited to solve these challenging problems, current research aims at shedding light on these fundamental questions.

The workshop has been enthusiastically received by the whole community as witnessed by the high number of registrations: the organizers had to select among the applicants due to the limited number of possible participants. Nevertheless, we successfully manage to have representatives of different communities and approaches.

Activities

Within the workshop program, various presentations reported a complete overview of the different platforms and experimental protocols which have been proposed to perform quantum simulations of lattice gauge theories. Moreover, the – to date – unique experiment going in this direction carried out on a

trapped ions quantum simulator has extensively reported, both in its experimental and theoretical aspects: in a pioneering experiment the group of R. Blatt in Innsbruck managed to show the building blocks of a quantum simulator for the Schwinger model. On the opposite side of the spectrum of the subjects belonging to this interdisciplinary field, the colleagues coming from the high-energy and lattice communities presented their view on the subject: they introduced stimulating open problems and possible points of contacts, resulting in an enhanced communication capabilities among the different communities and suggesting the possible next steps of the development of the quantum methods for lattice gauge theories. Finally, experts in tensor network methods working in the field presented their latest results and the open problems that they are facing, together with the future challenges they plan to attack. In particular, different presentations frankly and openly reported the challenges they are encountering to extend the present methods to higher dimensional systems, and the strategies that they are exploring to overcome them.

Conclusions and perspectives

The objectives of the workshop have been fully achieved: different actors coming from the different communities had an in-depth and fruitful discussion, which pointed out the major challenges for the future. Novel collaborations are insight, and a growing community of actors has been attracted to this new fascinating interdisciplinary field. It has become clear that the two major challenges are on the one hand the extension of tensor network method to higher dimensional systems, on the other hand, the scaling in the number of components of the quantum simulator for lattice gauge theories. These goals, although being highly challenging and surely not reachable in the immediate future, are pursued with clear strategies and effective tools and methods. No fundamental limitations, which would completely stop the pursued research program, are in sight. In conclusion, among the workshop attendees, there is a shared expectation that a consistent effort and investment of resources will result in the successful development of efficient novel methods to study lattice gauge theories which could perfectly complement the powerful methods developed in the last decades.

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