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Mainz Institute for Theoretical Physics

Quantum methods for lattice gauge theories calculations

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This topical workshop brought together the expertise of scientists on high-energy-physics, lattice calculations and scientists exploring the route toward quantum lattice calculations. The bridge between these two communities was surely beneficial to the current research program indicating possible critical aspects, and revealing new ideas and approaches based on decades of experience in lattice calculations. Two different dimensions were explored:

(i) 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 represent promising alternative numerical tools to address challenging questions in strongly correlated condensed matter and in LGTs.

(ii) 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 approaches (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 topical workshop was enthusiastically appreciated by the whole community as witnessed by the high number of registrations. There were representatives of different communities and approaches. Within the workshop program, various presentations gave a complete overview of the different platforms and experimental protocols which were proposed to perform quantum simulations of lattice gauge theories. Moreover, the currently unique experiment in this direction carried out on a trapped ions quantum simulator has extensively been reported, both in its experimental and theoretical aspects. In a pioneering experiment the group of Rainer 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, 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

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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 tackle. In particular, different presentations openly pointed out the challenges they are encountering to extend the present methods to higher dimensional systems, and the strategies that they are exploring to overcome them.

The objectives of the topical workshop were fully achieved. Different actors coming from the different communities had an in-depth and productive discussion, which emphasized the major challenges for the future. Novel collaborations are in sight, and a growing community of scientists has been attracted to this new fascinating interdisciplinary field. It has become clear that there are two major challenges: on the one hand the extension of tensor network method to higher dimensional systems and on the other hand, the scaling in the number of components of the quantum simulator for lattice gauge theories. These goals, although being very challenging and definitely not reachable in the near future, are pursued with clear strategies, effective tools and methods. There are no fundamental limitations which could completely stop the research program pursued. In conclusion, the workshop participants shared the expectation that a consistent effort and investment of resources will result in the successful develop-ment of efficient novel methods to study lattice gauge theories which can perfectly complement the powerful methods developed in the last decades.