MITP Topic Workshop

Quantum Methods for Lattice Gauge Theories (QMEL2022), 7-11 November 2022

Organizers: Mari Carmen Bañuls (MPQ), Alessio Celi (UAB), Karl Jansen (DESY) and Simone Montangero (Uni. Padova)

Gauge theories are a cornerstone of the current theoretical understanding of fundamental physics. They appear also as emergent theories in condensed matter models, and can give rise to puzzling phenomena, like confinement. Lattice gauge theories (LGT), their discrete formulation, were developed as an approach to facilitate the numerical, non-perturbative solution of such models. Traditional methods to solve LGT, based on Montecarlo techniques, have been able to produce impressive results, especially in the ambit of lattice QCD, where first-principle calculations of observable quantities, such as hadronic spectra, served to establish the potential of LGT for fundamental research. Nevertheless, scenarios like finite matter density or real time evolution escape the reach of these tools, and motivate a search for alternative strategies.

Quantum techniques, fastly developing over the last decade, have brought a new perspective onto lattice gauge theories, including quantum inspired algorithms for classical simulation and experimentally feasible proposals for quantum simulations. The workshop focused on recent progress in this area. To this end, more than 20 experts at different career stages were brought together for five days, presented their latest results and exchanged opinions during open discussion sessions.

The high energy community was represented by several participants. S. Bass discussed emergent gauge symmetries and their possible role in the Standard Model of particle physics. H. Lamm focused on the key aspects and estimated computational cost to solve LQCD on a quantum computer. That quantum information and computation ideas can be useful also for string theory problems and models was illustrated by the talks by M. Heller and E. Rinaldi. From the condensed matter side, other connections between quantum many-body and high energy physics were also suggested in talks by E. Tirrito or R. Verdel.

A significant focus of the workshop was discussing tensor network algorithms and their progress in the area of LGT. Some of the most relevant aspects discussed were techniques to improve the efficiency of tensor network simulations of LGT in two or more spatial dimensions (G. Cataldi), the encoding or elimination of fermionic degrees of freedom (P. Silvi) and the numerical simulation of out-of-equilibrium processes, in particular scattering (M. Rigobello).

Quantum simulation of LGT was another center of interest. From the theoretical point of view, different participants presented and discussed models that are potentially realizable in quantum engineered systems. To name a few examples, L. Tagliacozzo described the phase diagram of a discrete Abelian Higgs model in 1+1D, and the identification of an unconventional critical point. D. González-Cuadra and T. Zache discussed the potential of simulating LGT with qudits.

Consisting only of finite dimensional degrees of freedom, quantum link models (QLM) reveal as particularly attractive to be realized in quantum simulators, which was also reflected in some of the contributions (P. Fontana, P. Stornati). E. Rico discussed different aspects of quantum simulation of LGT with superconducting qubits.

The experimental aspect was represented by L. Tarruell, who discussed the realization of a one-dimensional topological gauge field theory using density dependent gauge fields in BEC experiments, and by M. Aidelsburger, who presented realizations of the fundamental building block of a U(1) LGT with ultracold atoms trapped in an optical lattice.

All in all, the workshop was successful. The participants enjoyed the activity, especially the opportunity to discuss among themselves, and the hospitality of the MITP. A significant number of actively participating young researchers testifies to the liveliness and future perspectives of the topic.