Symposium Quantum Simulators of Lattice Gauge Theories (SYLG)

jointly organized by
the Quantum Optics and Photonics Division (Q),
the Atomic Physics Division (A), and
the Particle Physics Division (T)

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Lattice gauge theories provide essentially the only theoretic way to access theories of fundamental constituents of matter (standard model, quantum chromodynamics, etc.) in an non-perturbative way. Still, many questions concerning these theories (in particular involving finite densities and temperatures) remain open. Recent developments in physics of ultracold atomic and molecular matter allow for the design and control of quantum many body systems that may serve as quantum simulators of various interesting theoretical models of condensed matter or high energy physics. In particular numerous proposals have been formulated and are being implemented in experiments, in which simple models of lattice gauge theories can be tested. The Symposium will confront quantum optics and high energy physics to discuss the further directions of this new rapidly developing area.

Overview of Invited Talks and Sessions

(Lecture room P 1)

Invited Talks

SYLG 1.1	Fri	11:00–11:30	P 1	**Quantum Simulation of Lattice Gauge Theories with Cold Atoms and Ions** — •Peter Zoller
SYLG 1.2	Fri	11:30–12:00	P 1	**Quantum Simulations with Cold Trapped Ions** — Esteban A. Martinez, Christine A. Muschik, Philipp Schindler, Daniel Nigg, Alexander Erhard, Markus Heyl, Philipp Hauke, Marcello Dalmonte, Thomas Monz, Peter Zoller, •Rainer Blatt
SYLG 1.3	Fri	12:00–12:30	P 1	**Studies of hot and dense nuclear matter at the Large Hadron Collider** — •Boleslaw Wyslouch
SYLG 1.4	Fri	12:30–13:00	P 1	**Lattice gauge theory beyond QCD** — •Claudio Pica

Sessions

SYLG 1.1–1.4	Fri	11:00–13:00	P 1	**Symposium Quantum Simulators of Lattice Gauge Theories**

SYLG 1: Symposium Quantum Simulators of Lattice Gauge Theories

Time: Friday 11:00–13:00 Location: P 1

Invited Talk SYLG 1.1 Fri 11:00 P 1

Quantum Simulation of Lattice Gauge Theories with Cold Atoms and Ions — •Peter Zoller — Institute for Theoretical Physics, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Innsbruck, Austria

We review recent theory proposals and experimental advances in quantum simulation of lattice gauge theories with quantum optical systems of cold atoms and ions, both from the perspective of condensed matter and high energy physics [1,2]. Our discussion starts with the lattice Schwinger model as 1+1 dimensional lattice QED, where we illustrate the challenge of implementing gauge invariance and the associated local conservation laws (Gauss laws) in cold atom implementations. We discuss analog and digital quantum simulation of the lattice Schwinger model both in a Wilson and quantum link formulation, and summarize recent experimental results [3] on real-time evolution of the Schwinger mechanism of spontaneous creation of electron-positron pairs on a few qubit ion trap quantum computer. In addition, we extend our discussion to quantum simulation of non-Abelian lattice gauge theories realized with atoms in optical lattices, and provide illustrations of simple models of quantum simulation of "nuclear physics".

[1] U.-J. Wiese, Annalen der Physik 525, 777 (2013) [2] E. Zohar, J.I. Cirac and B. Reznik, Rep. Prog. Phys. 79, 014401 (2015) [3] E. A. Martinez, C. A. Muschik, P. Schindler, D. Nigg, A. Erhard, M. Heyl, P. Hauke, M. Dalmonte, T. Monz, P. Zoller and R. Blatt, Nature 534, 516 (2016)

Invited Talk SYLG 1.2 Fri 11:30 P 1

Quantum Simulations with Cold Trapped Ions — Esteban A. Martinez[1], Christine A. Muschik[2,3], Philipp Schindler[1], Daniel Nigg[1], Alexander Erhard[1], Markus Heyl[2,4], Philipp Hauke[2,3], Marcello Dalmonte[2,3], Thomas Monz[2,3], Peter Zoller[1,2], and •Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck — [3]Institut für Theoretische Physik, Universität Innsbruck — [4]Physik Department, Technische Universität München

The quantum toolbox of the Innsbruck ion-trap quantum computer is applied to simulate the dynamics and to investigate the propagation of entanglement in a quantum many-body system represented by long chains of trapped-ion qubits [1]. Moreover, using the quantum toolbox operations, universal (digital) quantum simulation was realized with a string of trapped ions [2]. Here we report the experimental demonstration of a digital quantum simulation of a lattice gauge theory, by realizing (1 + 1)-dimensional quantum electrodynamics (the Schwinger model) on a few-qubit trapped-ion quantum computer [3]. We map the original problem to a spin model by eliminating the gauge fields in favor of exotic long-range interactions, which can be directly and efficiently implemented on an ion trap architecture.

[1] P. Jurcevic et al., Nature **511**, 202 (2014).
[2] B. P. Lanyon et al., Science **334**, 57 (2011).
[3] E. A. Martinez et al., Nature **534**, 516 (2016).

Invited Talk SYLG 1.3 Fri 12:00 P 1

Studies of hot and dense nuclear matter at the Large Hadron Collider — •Boleslaw Wyslouch — MIT, Cambridge, MA USA

Over the last few years the Large Hadron Collider spent several months colliding heavy nuclei and protons with heavy nuclei at relativistic energies. The extremely hot matter created in these collisions exhibits unusual properties. The high density plasma of quarks and gluons behaves like a strongly interacting liquid and it absorbs very energetic partons. We use large particle detectors and various experimental techniques to understand its properties. In this talk I will introduce the overall research program and present the latest results.

Invited Talk SYLG 1.4 Fri 12:30 P 1

Lattice gauge theory beyond QCD — •Claudio Pica — CP3-Origins, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark

Simulations of lattice gauge theories can play a key role in advancing our theoretical understanding of strongly coupled gauge theories relevant for extensions of the Standard Model and the LHC physics program.

In this talk I will review the state of BSM lattice studies aimed to chart the phase diagram of non-supersymmetric gauge theories and to search for new models of strong dynamics beyond QCD.