# Q 15: Quantum Information (Quantum Computing and Simulation)

Time: Tuesday 10:30–12:30 Location: Q-H12

**Invited Talk** Q 15.1 Tue 10:30 Q-H12

**A hybrid quantum classical learning agent** — •Sabine Wölk — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Machine learning and quantum information become more and more important in our digital world. An important paradigm within machine learning is reinforcement learning. Here, a decision-making entity called agent solves a task by interacting with its environment. The agent updates its behaviour, and thus learns, by using the obtained feedback it receives from the environment. We can speed up the learning if the agent and its environment can be transformed into corresponding quantum systems interacting with each other.

We have developed a hybrid quantum classical learning agent which combines quantum exploration of the environment with classical behavior updates [1,2]. In this way, we can achieve a quadratic speedup in learning. In this talk, I will explain the main features of this hybrid learning agent and discuss possible applications as well as first proof-of-principle experiments.

[1] A. Hamann and S. Wölk, Performance analysis of a hybrid agent for quantum-accessible reinforcement learning, arXiv: 2107.14001.

[2] V. Saggio, B. Asenbeck, A. Hamann, T. Strömberg, P. Schiansky, V. Dunjko, N. Friis, N. C. Harris, M. Hochberg, D. Englund, S. Wölk, H. J. Briegel, and P. Walther, Experimental quantum speed-up in reinforcement learning agents, Nature 591, 229 (2021).

Q 15.2 Tue 11:00 Q-H12

**Numerical optimization and demonstration of amplitude-modulatedpulses for microwave-driven entanglement-gates** — •Markus Duwe[1,2], Nicolas Pulido-Mateo[1,2], Hardik Mendpara[1,2], Giorgio Zarantonello[3], Ludwig Krinner[1,2], Amado Bautista-Salvador[1,2], Klemens Hammerer[4], Reinhard Werner[4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA — [4]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover, Germany

A universal set of quantum gates requires entangling operations with infidelities below the fault-tolerance threshold [1]. Trapped ions are one of the leading platforms approaching the required gate fidelities [2]. For trap-integrated microwave gate mechanisms, amplitude modulation of the gate drive has shown an increased of the resilience of two-qubit entangling operations against motional mode drifts [3]. Here we discuss the numerical optimization and experimental realization of pulse envelopes for the Mølmer-Sørensen entangling gate. The method allows the trajectory in phase space to be insensitive to chosen errors, such as trap and pulse parameters. We report infidelities approaching $10^{-3}$ with faster operation than previously shown in our experiment.

[1] E. Knill, Nature **434**, 39 (2005)

[2] J. Gaebler *et al.*, Phys. Rev. Lett. **117**, 060505 (2016)

[3] G. Zarantonello *et al.*, Phys. Rev. Lett. **123**, 260503 (2019)

Q 15.3 Tue 11:15 Q-H12

**Non-classical features of a multiparticle bosonic state propagating in an integrated network** — •federico pegoraro, philip held, syamsundar de, sonja barkhofen, jan sperling, benjamin brecht, and christine silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

According to Schrödinger equation, the evolution of a quantum system is governed by a unitary transformation. In light of this premise, the development of new protocols and platforms capable of probing the properties of unitary operations has a key role in a large range of fields from physics to information science. Among all the possible evolutions, Quantum Walks (QWs) have been proved to be a powerful tool within the framework of quantum information and computation. In particular, inhomogeneous and noisy QWs have been largely investigated. Our contribution finds itself along this direction: it is in fact our aim to exploit a fully reconfigurable integrated photonic network, capable to generate and probe a large variety of unitary operations in a reliable and efficient way, in order to implement QW evolutions with a certain degree of inhomogeneities and probe the properties of non-classical correlation of a bosonic multi-particle quantum state that propagates in our network.

Q 15.4 Tue 11:30 Q-H12

**Mimimal number of couplings and local controls for universal quantum computing** — •Fernando Gago Encinas, Monika Leibscher, David Pohl, Daniel Basilewitsch, and Christiane Koch — Freie Universität Berlin

Universal quantum computing requires evolution-operator controllability on the circuits used as a platform to perform every possible quantum logic gate. Since we know how to decide for a given system whether it is controllable or not, we can ask how many local controls and 2-qubit couplings are needed. This information is key for building larger and larger devices because these controls and couplings are very expensive in terms of the physical space in the circuit and the calibrations required. We analyze different schemes for a controllable qubit array that minimize these couplings and controls using a special controllability test derived from graph theory. We find that some specific couplings yield better results for controllability and identify some possible candidates to design a scalable modular circuit.

Q 15.5 Tue 11:45 Q-H12

**Towards Measurement-Based Variational Quantum Simulation of the Multi-Flavor Schwinger Model** — •Stephan Schuster[1], Stefan Kühn[2], Tobias Hartung[2,3], Lena Funcke[4], Marc-Oliver Pleinert[1], Joachim von Zanthier[1], and Karl Jansen[5] — [1]Friedrich-Alexander University Erlangen-Nürnberg (FAU), Staudtstrasse 1, 91058 Erlangen, Germany — [2]Computation-Based Science and Technology Research Center, The Cyprus Institute, 20 Kavafi Street, 2121 Nicosia Cyprus — [3]Department of Mathematical Sciences, University of Bath, Bath BA2 7AY, United Kingdom — [4]Center for Theoretical Physics, MIT Department of Physics, 77 Massachusetts Avenue, Cambridge MA 02139 USA — [5]NIC, Desy Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany

Recently, the first measurement-based variational quantum simulation has been proposed, which employs a one-way quantum computation instead of a quantum circuit for the simulation. This shifts the experimental challenge of complex gate realizations to the generation of a entangled cluster state which is then locally measured. In our work, we developed a variational one-way quantum computing simulation protocol for the multi-flavor lattice Schwinger model with a flavor-dependent chemical potential, considering model-specific symmetries in our quantum algorithm. The flavor-dependent chemical potential increases the model complexity but also allows us to investigate first-order energy phase transitions in dependence of the chemical potential. First classical simulation results of our protocol look very promising and allowed us to determine several critical points in the phase diagram.

Q 15.6 Tue 12:00 Q-H12

**Fehlertolerante Paritätsauslese auf einem Quantenprozessor mit Ionenkristallen** — •Janine Hilder, Daniel Pijn, Oleksiy Onishchenko, Alexander Stahl, Maximilian Orth, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Quantenprozessoren basierend auf gefangenen Ionen sind einer der vielversprechendsten Kandidaten für die Realisierung eines skalierbaren Quantenprozessors. Um eine fehlertolerante Quanteninformationsverarbeitung zu realisieren, ist es von entscheidender Bedeutung, Quantenfehlerkorrektur durchführen zu können. Ein wesentlicher Baustein ist die Erkennung von Fehlern durch Stabilisatormessungen, ohne den Quantenzustand der Datenbits zu zerstören [1,2]. Diese wurde kürzlich auf shuttlingbasierten Quantenprozessoren experimentell demonstriert [3,4]. Wir erreichen eine Verbesserung der Paritätsauslesegüte von 92.3(2)% auf 93.2(2)% bei Selektierung aufgrund des Flag-Qubits, welches Datenqubit kompromittierende Fehler während der Stabilisatormessung anzeigt. Zusätzlich zeigen wir die Erzeugung von Verschränkung auf allen Ionen, die an dieser fehlertoleranten Paritätsauslese beteiligt sind.

[1] A. Bermudez et al., Phys. Rev. X 7, 041061 (2017)

[2] A. Rodriguez-Blanco et al., PRX Quantum 2, 020304 (2021)

[3] J. Hilder et al., arXiv:2107.06368 (2021)

[4] C. Ryan-Anderson et al., arXiv:2107.07505 (2021)

Q 15.7 Tue 12:15 Q-H12

**Compiler zur Register-Rekonfiguration eines Ionenfallen-Quantencomputers** — •Janis Wagner[1], Janine Hilder[1], Christian Melzer[1], Björn Lektisch[1], Ulrich Poschinger[1], André Brinkmann[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Zentrum für Datenverarbeitung, Universität Mainz, Anselm-Franz-von-Bentzel-Weg 12, 55128 Mainz, Germany

Ionenfallen mit laserbasierten Gattern sind aufgrund ihrer hohen Operationsgüte ein möglicher Kandidat für Quantencomputer. Die Architektur einer segmentierten Paul-Falle mit mehreren Speicher- und Prozessorregionen, zwischen denen die Ionen mittels zeitabhängiger Spannungsrampen bewegt werden können, erlaubt eine Rekonfigurierbarkeit der Register und damit eine Skalierung jenseits der reinen Kristallvergrößerung. Um eine Gattersequenz effizient auf einer solchen Architektur ausführen zu können, muss aus dieser eine sinnvolle Startkonfiguration der Ionen ermittelt werden, sowie eine Rekonfigurationssequenz berechnet werden. Der vorgestellte Shuttling-Compiler implementiert einen Algorithmus, der dies in polynomieller Abhängigkeit für Anzahl der Qubits und Gatter bewerkstelligt.