Q 24: Quantum Computing Implementations (joint session QI/Q)

Time: Tuesday 14:00–15:30 Location: HS II

Q 24.1 Tue 14:00 HS II

Theory and Experimental Demonstration of Wigner Tomography of Unknown Unitary Quantum Gates — •Amit Devra[1], Leo Van Damme[1], Frederik vom Ende[2], Emanuel Malvetti[1], and Steffen J. Glaser[1] — [1]Technical University of Munich — [2]Freie University Berlin

We investigate the tomography of unknown unitary quantum processes within the framework of a finite-dimensional Wigner-type representation. This representation provides a rich visualization of quantum operators by depicting them as shapes assembled as a linear combination of spherical harmonics. These shapes can be experimentally tomographed using a scanning-based phase-space tomography approach. However, so far, this approach was limited to known target processes and only provided information about the controlled version of the process rather than the process itself. To overcome this limitation, we introduce a general protocol to extend Wigner tomography to unknown unitary processes. This new method enables experimental tomography by combining a set of experiments with classical post-processing algorithms introduced herein to reconstruct the unknown process. We also demonstrate the tomography approach experimentally on IBM quantum devices and present the specific calibration circuits required for quantifying undesired errors in the measurement outcomes of these demonstrations.

Q 24.2 Tue 14:15 HS II

High Energy Quantum Simulation on a Trapped-Ion Quantum Processor — •Christian Melzer[1], Stephan Schuster[2], Diego Alberto Olvera Millán[1], Janine Hilder[1], Ulrich Poschinger[1], Karl Jansen[3], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg — [3]Center for Quantum Technology and Applications, DESY Zeuthen

Currently, quantum processors are noisy and only exhibit few qubits. Still, there are executable applications that show potential for future advantages. We investigate the multi-flavor Schwinger model with nonzero chemical potential. This model stems from the field of high energy physics [1] and describes a phase transition in quantum electrodynamics in one space and one time dimension. For classical computing, this fermionic simulation becomes intractable even for small system sizes due to the notorious sign problem. Using our shuttling-based trapped-ion quantum processor [2], we solve instances of this problem by a variational approach (VQE). Thereby, we find the lowest energy eigenstate of the system and determine the phase transition.

[1] Schuster et al., Phys. Rev. D 109, 114508 (2024)
[2] Hilder et al., Phys. Rev. X 12, 011032 (2022)

Q 24.3 Tue 14:30 HS II

Demonstrations of system-bath physics on gate-based quantum computer — Pascal Stadler, Matteo Lodi, Andisheh Khedri, Rolando Reiner, Kirsten Bark, Nicolas Vogt, Michael Marthaler, and •Juha Leppäkangas — HQS Quantum Simulations GmbH, Rintheimer Straße 23, 76131 Karlsruhe, Germany

We develop a quantum algorithm that can be used to perform algorithmic cooling on noisy quantum computers. The approach utilizes inherent qubit noise to simulate the equilibration of an interacting spin system towards its ground state, when coupled to a simulated dissipative auxiliary-spin bath. We test the algorithm on IBM-Q devices and demonstrate the relaxation of system spins to ferromagnetic and antiferromagnetic ordering, controlled by the definition of the system Hamiltonian. The ordering is stable as long as the algorithm is run. We are able to perform cooling and state stabilization for global systems of up to three system spins and four auxiliary spins.

Q 24.4 Tue 14:45 HS II

Variational quantum algorithm based self-consistent calculations for the two-site DMFT model on noisy quantum computing hardware — Jannis Ehrlich, •Daniel F. Urban, and Christian Elsässer — Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany

Dynamical Mean Field Theory (DMFT) is one of the powerful computational approaches to study electron correlation effects in solid-state materials and molecules. Its practical applicability is, however, limited by the quantity of numerical resources required for the solution of the underlying auxiliary Anderson impurity model. Here, the possibility of a one-to-one mapping between electronic orbitals and the state of a qubit register suggests a significant computational advantage for the use of a Quantum Computer (QC) for solving DMFT models. In this work we present a QC approach to solve a two-site DMFT model based on the Variational Quantum Eigensolver (VQE) algorithm. We discuss the challenges arising from stochastic errors and suggest a means to overcome unphysical features in the self-energy. We thereby demonstrate the feasibility to obtain self-consistent results of the two-site DMFT model based on VQE simulations with a finite number of shots. We systematically compare results obtained on simulators with calculations on the IBMQ Ehningen QC hardware.

Q 24.5 Tue 15:00 HS II

Robust Microwave-Driven Quantum Gates in a Cryogenic Surface-Electrode Trap — •Judi Parvizinejad, Sebastian Halama, Giorgio Zarantonello, Celeste Torkzaban, and Christian Ospelkaus — Institute für Quantenoptik, Leibniz University Hannover, Welfengarten 1, 30167 Hannover

A fault-tolerant quantum computer requires a large number of qubits with high gate fidelities, ability to generate entanglement between many qubits, and sufficiently long coherent time. Surface-electrode ion traps [1] have emerged as a promising solution due to their high gate fidelities, long coherence times, and the ability to physically move them around into different zones, which are key requirements for scalable multi-quit operations [1, 4]. Alongside laser-based techniques, microwave-driven gates [2] are promising for advancing fault-tolerant quantum computing. In our cryogenic experiments, 9Be+ ions are confined at a distance of 70 μm above a surface-electrode Paul trap where a strong microwave gradients field generated by an embedded microwave meander is for driving entangling gates [3]. We will present our recent advancements in achieving high-fidelity microwave-driven gate operations, and will share our plan for demonstrating simple quantum error correction algorithms for quantum metrology.

[1] C. Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008). [2] C. Ospelkaus et al., Nature 476, 181-184 (2011). [3] M. Carsjens et al., Appl. Phys. B 114, 243 (2014). [4] D. Kielpinski et al., Nature, 417, 709-711 (2002).

Q 24.6 Tue 15:15 HS II

Quantum teleportation of a Bell state via cluster states on IBM Quantum — •Branislav Ilich[1,2] and Nikolay Vitanov[1,2] — [1]Sofia University St. Kliment Ohridski — [2]Center for Quantum Technologies

We report experimental results on the teleportation of a two-qubit entangled Bell state across a six-qubit entangled system on ibm_sherbrooke. The teleportation protocol begins with the generation of a four-qubit cluster state on Bob's subsystem and the preparation of a two-qubit Bell state on Alice's subsystem. The entangled state is then teleported to the last two qubits of Bob's cluster state through a series of controlled-NOT (CNOT) gates.

To maximize the fidelity of the protocol, we implemented targeted optimizations within IBM's transpiler, enabling precise control over gate placement and error mitigation. These modifications were critical in achieving a protocol fidelity of 90%, which represents the upper limit for IBM's quantum hardware.

Our findings demonstrate the feasibility of reliably teleporting entangled states across distributed quantum systems and highlight the importance of hardware-aware optimization strategies in achieving high-fidelity quantum information processing. This work serves as a step forward in scaling entanglement distribution protocols, with implications for quantum communication and distributed quantum computing.