Q 51: Quantum Computing and Simulation I (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: AP-HS

Q 51.1 Thu 11:00 AP-HS

Simulating scalar quantum field theories on integrated photonics platforms — •Mauro D'Achille[1], Martin Gärttner[1], and Tobias Haas[2] — [1]Friedrich Schiller Universität, Jena, Germany — [2]Université Libre de Bruxelles, Bruxelles, Belgium

Photonic multimode systems are an emerging quantum simulation platform ideally suited for emulating non-equilibrium problems in quantum field theory. I will present a new decomposition*for the time evolution generated by a large class of field-theoretic quadratic Hamiltonians*in terms of optical elements. The peculiarity of this decomposition consists in the way the time parameter is taken into account. Indeed, for such a class, it is always possible to decouple the time evolution in time-dependent phase shift transformations by means of a proper time-independent symplectic transformation composed by squeezers and beam splitters. I will conclude with physically relevant examples and applications aimed to analyze and simulate how the entanglement entropy associated to local and non-local theories spreads over time.

Q 51.2 Thu 11:15 AP-HS

Photonic Qubit Z-Gate Scheme from Scattering with Atomic Vapors in a 1D Waveguide Slot — •Evangelos Varvelis and Joachim Ankerhold — Institute for complex quantum systems, University of Ulm

Photonic quantum computing offers a promising platform for quantum information processing, benefiting from the long coherence times of photons and their ease of manipulation. This paper presents a scheme for implementing a deterministic Z-gate for frequency-encoded photonic qubits, leveraging a silicon slot waveguide filled with thermal rubidium vapor. This system enhances atom-photon interactions via the Purcell effect, allowing dynamic control of nonlinearity at the few-photon level while operating efficiently at room temperature. Using a transfer matrix approach, we develop a protocol for Z-gate operation, demonstrating its robustness against non-waveguide mode coupling and disorder. Finally, we will relax the idealized assumption of monochromatic light in favor of finite bandwidth pulses. Despite these realistic considerations, our results indicate high fidelity for the proposed Z-gate.

Q 51.3 Thu 11:30 AP-HS

Modeling Fabrication Tolerances in RF Junctions for Register-Based Trapped-Ion Quantum Processors — •Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Mohammad Masum Billah[1], Axel Hoffmann[1,2], Giorgio Zarantonello[1,3], and Christian Ospelkaus[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Germany — [3]QUDORA Technologies GmbH, Braunschweig, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Radiofrequency (RF) junctions are crucial elements for enabling two-dimensional structures in the Quantum Charge-Coupled Device (QCCD) architecture and are thus essential for scaling trapped-ion quantum processors. As the resulting pseudopotential and its attributes depend on the specific junction geometry, they are susceptible to fabrication tolerances. To address this challenge, our study incorporates common microfabrication errors, including feature over- and underexposure and corner rounding, into the simulation models. Utilizing this comprehensive toolset, we evaluate an optimized RF X-junction in a surface-electrode trap, assessing its robustness against typical errors encountered in the multilayer microfabrication process.

Q 51.4 Thu 11:45 AP-HS

Local Control in a Sr quantum computing demonstrator — •Kevin Mours[1,3], Eran Reches[1,3], Robin Eberhard[1,3], Dimitrios Tsevas[1,3], Zhao Zhang[1,3], Lorenzo Festa[1,3], Max Melchner[1,2,3], Andrea Alberti[1,2,3], Sebastian Blatt[1,2,3], Johannes Zeiher[1,2,3], and Immanuel Bloch[1,2,3] — [1]Max-Planck Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany — [3]Munich Center for Quantum Science and Technology, 80977 Munich, Germany

Digital quantum simulations and quantum error correction protocols require the application of local gates. We demonstrate such local control in a neutral atom array platform by locally shifting the qubit's frequency using off-resonant light. We show precise, highly parallel, local Z-rotations with low crosstalk. Together with global X-rotations, which have been optimized for minimizing motional entanglement using optimal control, this approach can be used to locally implement universal single-qubit operations.

Q 51.5 Thu 12:00 AP-HS

Programmable Fermionic Quantum Simulation with Ground-State Optical Tweezer Arrays — •Jin Zhang[1], Naman Jain[1], Marcus Culemann[1,2], Kirill Khoruzhii[1,2], Jun Ong[1], Xinyi Huang[1], Pragya Sharma[1], and Philipp Preiss[1,3] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Ludwig-Maximilians-Universität, Munich — [3]Munich Center for Quantum Science and Technology

Programmable quantum simulation using ultracold fermions in optical lattices has emerged as a powerful approach to investigating many-body phenomena and non-equilibrium dynamics. Nonetheless, the initialization of arbitrary quantum states remains a significant challenge. Recent advances in optical tweezer arrays offer a promising solution for creating programmable initial states. Leveraging the reconfigurability of tweezers, atoms can be arranged into arbitrary spatial configurations. When combined with optical lattices and site- and spin-resolved imaging techniques, this setup establishes an ideal platform for quantum information studies. In this presentation, we demonstrate the rapid and high-fidelity preparation of optical tweezer arrays, achieving deterministic trapping of fermionic atom pairs in the motional ground state of each tweezer. We showcase spin-dependent free-space imaging, efficient loading and evaporation protocols, as well as deterministic control of atom numbers within the tweezer arrays. These advancements expand the scope of quantum simulation beyond ground-state Hubbard physics, enabling exploration of quantum chemistry and fermionic quantum information processing.

Q 51.6 Thu 12:15 AP-HS

Towards cavity-mediated entanglement within an atomic array — •Johannes Schabbauer[1], Stephan Roschinski[1], Franz von Silva-Tarouca[1], and Julian Leonard[1,2] — [1]TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Stadionallee 2, 1020 Wien, Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Creating multi-particle entangled states deterministically is one of the big challenges for quantum information processing. While this was achieved locally in several systems, for instance with arrays of optical tweezers using Rydberg interactions between atoms, we set up an experiment to engineer non-local interactions between single atoms in optical tweezers by strong coupling to an optical cavity. In our experiment we reach the single-atom strong-coupling regime using a fiber cavity (C=80). Our cavity setup also enables good optical access for high resolution microscopes, which are used for trapping, site-resolved imaging and addressing of single atoms in optical tweezers. Our experiment enables us to study multi-particle entangled states and many-body systems with programmable interactions. The dispersive shift of the cavity resonance can be used to perform non-destructive measurements and to implement protocols for dissipative state preparation.

Q 51.7 Thu 12:30 AP-HS

Neutral Ytterbium atoms in optical tweezers for quantum computing and simulation — •Jonas Rauchfuss[1], Tobias Petersen[1], Nejira Pintul[1], Clara Schellong[1], Jan Deppe[1], Carina Hansen[1], Koen Sponselee[1], Alexander Ilin[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center of Optical Quantum Technologies University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

In recent years, neutral atoms have emerged as a promising platform for quantum computing and quantum simulation, featuring scalable and highly coherent quantum systems with high-fidelity single-atom control as well as engineerable strong long range interactions. We use the alkaline-earth-like element ytterbium, whose fermionic isotope ^{171}Yb features a rich level structure, allowing e.g. for optical trapping and manipulation of Rydberg states, as well as metastable states, offering the realisation of sophisticated qubit schemes.

In this talk, we introduce our experimental setup, show characterisations of tweezer loading and imaging, and present our current progress towards building a neutral-atom quantum simulator. We further present efforts to overcome known limitations of current quantum computation and simulation platforms, like arbitrary atom addressing techniques and efficient suppression of servo induced laser noise for highest fidelity excitation schemes.

Q 51.8 Thu 12:45 AP-HS

Eigen-SNAP gate of two photonic qubits coupled via a transmon — •Marcus Meschede[1] and Ludwig Mathey[1,2,3] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

In the pursuit of robust quantum computing, bosonic qubits encoded in cavity modes have emerged as a promising platform. Full control over single bosonic qubits can be achieved through bosonic mode displacement drives and the driving of a dispersively coupled ancilla. However, the implementation of two-qubit gates depends heavily on the specifics of the coupling between the two bosonic modes. Building on the design of the selective number-dependent phase (SNAP) gate for the single cavity system, we extend this concept to develop the eigen-SNAP gate. This gate operates on the eigenmodes of the two coupled bosonic modes. Using the eigen-SNAP gate, we implement an entangling gate on a system of two logical bosonic qubits. Further, we use numerical optimization to determine the optimal version of the entangling gate $\sqrt{\text{SWAP}}$. The fidelities of these optimal protocols are limited by the coherence times of the system's components. The entangling gate is compatible with bosonic error-correctable encodings and is agnostic to the specific encoding within this class of logical qubits, paving the way to continuous variable quantum computing.