Q 68: Quantum Computing and Simulation II

Time: Friday 14:30–16:30 Location: HS 1199

Q 68.1 Fri 14:30 HS 1199

Single atoms in a cavity: a platform for photonic graph states generation — Philip Thomas, Leonardo Ruscio, •Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Photonic graph states are powerful resources for numerous quantum information applications, from pure quantum computation, with so-called measurement based quantum computing (MBQC), to the one-way quantum repeater for quantum communication. However, generating graph states experimentally is a tremendous challenge. The cavity QED toolbox offers all that is needed to efficiently generate graph states. Using a single atom in an optical cavity we have shown the generation record-size Greenberger-Horne-Zeilinger (GHZ) states and linear cluster states [1]. With only one photon emitter, the type of graph states one can generate remains limited though. Hence, to go beyond, we show that elementary graph states – generated by two independent atoms – can be fused into more complex graph states, such as ring states, used for error correction, and tree states for the one-way quantum repeater [2]. This concept can be extended to an even larger number of atoms, providing a universal platform. Hence, these demonstrations are moving forward the potential of graph states for realistic applications in quantum information.

[1] P. Thomas *et al.*, Nature **608**, 677-681 (2022).
[2] P. Thomas *et al.*, Under review (2024).

Q 68.2 Fri 14:45 HS 1199

Towards Photonic Cluster-State Generation — •Thomas Häffner, Siavash Qodratipour, and Oliver Benson — Nano-Optik, Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Deutschland

Fusion-based linear optical quantum computing (LOQC) is a promising platform, where the complexity is shifted from two-qubit gates to the generation of a resource state, a highly entangled cluster state [1]. As the goal is an integrated photonic implementation of such a quantum computer, our experiment is completely in optical fibers. Therefore a suitable choice for qubits is the time-bin degree of freedom of single photons. Time-bin entangled pairs of two single photons are generated in a type-II periodically-poled LiNbO3 waveguide by a pulsed laser source [2]. We show Hong-Ou-Mandel (HOM) interference between two photons of two subsequent time-multiplexed pairs. The visibility of the HOM interference is a measure of the pureness and indistinguishability of single photons, which are necessary to efficiently entangle photons into cluster states. Multi-pair generation decreases the visibility of the HOM interference. A time-multiplexed pseudo-photon-number-resolving detector was built and is used to optimize the probability of generating exactly one photon pair per pump pulse. Recent results of the experimental implementation towards a time-bin fusion gate will be presented. [1] Bartolucci, S. et al. Fusion-based quantum computation. Nat. Commun. 14, 912 (2023) [2] Montaut, N. et al. High-Efficiency Plug-and-Play Source of Heralded Single Photons. Phys. Rev. Applied 8, 024021 (2017)

Q 68.3 Fri 15:00 HS 1199

Entanglement Transfer Properties in Time-Multiplexed Discrete-Time Quantum Walks — •Jonas Lammers, Federico Pegoraro, Philip Held, Nidhin Prasannan, Fabian Schlue, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Entanglement, as it arises from quantum mechanics, is a powerful resource underlying many protocols demonstrating quantum advantage. Interestingly, the inseparability of multiple degrees of freedom underlying entanglement has a classical analog exhibited for example by coherent laser light. As this classical inseparability (aka. modal entanglement) cannot be used to violate local realism, it has a controversial role in the field of quantum information science. In this work, we contribute to this discussion by studying how modal entanglement interacts with quantum entanglement between two photons when subjecting one photon to a quantum walk evolution. For this purpose we generate two polarization entangled photons. One of which we send to a free-space time-multiplexed discrete-time quantum walk (QW). Here we investigate how the modal entanglement generated via the QW transfers multi-particle entanglement from the initial polarization-polarization towards the position-polarization encoding spanning both photons. For this purpose, we perform two photon polarization tomography at each individual position of the QW. We further developed an original measure which reveals signatures of multi-particle entanglement in conditioned position distributions.

Q 68.4 Fri 15:15 HS 1199

Implementation of a scalable quantum network node — •Matthias Seubert[1], Lukas Hartung[1], Stephan Welte[2], Emanuele Distante[1], and Gerhard Rempe[1] — [1]Max- Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich

For many envisioned applications of quantum networks, efficient and scalable quantum nodes are needed. A promising candidate are single neutral atoms trapped at the center of an optical resonator. While this architecture has proven its capabilities for storing and processing quantum information [1], probabilistic loading limits the number of individual controllable qubits to two. Optical tweezers by contrast, have demonstrated deterministic loading and a high degree of scalability [2].

In this talk, we show the merging of an optical cavity setup in the strong coupling regime with an optical tweezers setup. ^{87}Rb atoms are loaded at the center of a resonator and transferred into an optical tweezers array. Exploiting movable tweezers, individual atoms are rearranged in predefined atomic patterns with sub-wavelength precision. Afterwards we load the atoms into a 2D optical lattice. In this manner, we show a significant increase of preparing a deterministic number of simultaneously coupled atoms at predefined positions. Furthermore, we demonstrate the addressing capabilities of our setup by consecutively generating photons from individual atoms. In the future, this setup will be used to efficiently generate atom-photon entanglement.

[1] A. Reiserer and G. Rempe, Rev. Mod. Phys. 87, 1379 (2015)
[2] D. Barredo et al., Science 354, 6315 (2016)

Q 68.5 Fri 15:30 HS 1199

Robust quantum-network nodes through real-time noise mitigation — •Yang Wang[1,2], Sjoerd Loenen[2], Barbara Terhal[2,3], and Tim Taminiau[2] — [1]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany — [2]QuTech, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands — [3]JARA Institute for Quantum Information, Forschungszentrum Juelich, D-52425 Juelich, Germany

The nitrogen-vacancy (NV) center in diamond and other solid-state defect centers hold great potential for constructing quantum networks. NV centers can be remotely connected through entanglement via photonic links. Furthermore, by utilizing the electronic spin of the NV center to control associated nuclear spins, a small multi-qubit register can be formed. However, reliably storing entangled states while generating new entanglement links poses a significant challenge when scaling towards large networks. In this study, we propose a method that utilizes spectator qubits to mitigate noise on stored quantum states in real time. We consider a single NV center with multiple nuclear-spin qubits, and some nuclear spins are selected as spectator qubits that are not entangled with other nuclear spins serving as data qubits. The spectator qubits are initialized in a phase-sensitive state, and measuring them after sequences of optical entanglement attempts allows us to infer the stochastic phases acquired by the data qubits without additional operations on them. The spectator qubit approach is flexible and simple, and our experiments demonstrate that spectator qubits may be a useful tool for realizing robust quantum-network nodes.

Q 68.6 Fri 15:45 HS 1199

Two-qubit encoding strategy for a continuous quantum system — •Sebastian Luhn and Matthias Zimmermann — DLR e.V., Institut für Quantentechnologien, Ulm

Bosonic codes employ particular states of an infinite-dimensional Hilbert space to encode a qubit within a continuous quantum system. Despite the enormous resources available in a continuous quantum system [1], typical encodings only exist for single qubits [2]. Here we go one step further and present an encoding for two qubits (four states), which protects against errors in the shift of the canonical variables q and p. Furthermore, we present possible implementations of common single and two-qubit operations, based on particular symmetry operations for continuous quantum states represented by a square lattice in phase space.

[1] Lloyd, S. and Braunstein, S. (1999). Quantum Computation over Continuous Variables Phys. Rev. Letters, Vol. 82, No. 8

[2] Gottesman, D., Kitaev, A., and Preskill, J. (2001). Encoding a qubit in an oscillator. Phys. Rev. A, 64:012310

Q 68.7 Fri 16:00 HS 1199

Programmable high-dimensional mode-sorting of time-frequency states of single photons — •Laura Serino, Abhinandan Bhattacharjee, Michael Stefszky, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

The time-frequency (TF) degree of freedom of single photons provides high-dimensional encoding alphabets that can enhance quantum information science by increasing the robustness and capacity of quantum information carriers. These alphabets are generally classified into frequency bins, time bins and temporal modes, each coming with its own unique challenges and advantages. Simultaneously manipulating or detecting multiple single-photon TF modes and their superpositions is a challenging task, and most experimental demonstrations rely on complex interferometric setups or on a combination of phase modulators and pulse shapers, which are bound to a specific encoding alphabet.

In this work, we present for the first time programmable high-dimensional mode-sorting of single-photon-level TF states, achieved through a multi-output quantum pulse gate (mQPG). We demonstrate high-fidelity simultaneous high-dimensional projections onto temporal modes, frequency bins and time bins, where the encoding alphabet is changed programmatically via pulse shaping. For each encoding alphabet, we demonstrate projections onto multiple superposition bases, paving the way for practical applications in quantum information science.

Q 68.8 Fri 16:15 HS 1199

Towards solving Computer Vision optimization problems on an ion-trap-based quantum computer — •Florian Köppen[1], Sebastian Becker[3], Marcel Seelbach Benkner[2], Michael Möller[2], and Christof Wunderlich[1] — [1]Dept. Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen, Germany — [2]Dept. Informatik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen, Germany — [3]Mathematisch-Naturwissenschaftliche Fakultät, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Many problems in computer vision are optimization problems with quadratic cost functions - quadratic assignment problems (QAP) - which are NP-hard and are solved on classical computers by heuristics and relaxation algorithms. A QAP can be mapped onto an Ising-type Hamiltonian, which in turn could in principle be solved efficiently and exactly on a quantum computer by quantum annealing. With the help of magnetic gradient-induced coupling (MAGIC) between trapped ion-qubits, the long-range all-to-all interaction of the Ising Model is realized[1]. Here, we present an algorithm translating a QAP into the physical coupling between qubits and further into concrete parameter settings of a microstructured, segmented ion trap. This work is guided by using quantum annealing with trapped ions for solving pertinent problems in computer vision. [1] Pilz et al., Sci. Adv. 2 (7) 2016, e1600093