Q 37: Poster III

Time: Wednesday 17:00–19:00 Location: Tent B

Q 37.1 Wed 17:00 Tent B

A cryo-compatible, high-finesse all-fibre microcavity for REI spectroscopy — •Nicholas Jobbitt[1,4], Jannis Hessenauer[1,4], Evgenij Vasilenko[2,4], Vishnu Unni C.[1,4], Barbora Brachnakova[3,4], Senthil Kuppusamy[2,3,4], Mario Ruben[2,3,4], and David Hunger[2,3,4] — [1]Physikalisches Institut — [2]Institut für Quanten Materialien und Technologien — [3]Institute of Nanotechnology — [4]Karlsruher Institut für Technologie, Karlsruhe, Germany

Quantum technologies promise to enhance our current classical computing and communication infrastructure. Rare-earth ion (REI) based solid-state systems are ideal for this purpose due to the exceptional optical (4 ms) and spin (6 h) coherence times of their 4f → 4f transitions. However, key obstacles encountered while developing an efficient light-matter interface for quantum technologies using REI based solid-state systems are their long optical lifetimes ($T_{1,opt}$ ∼ms) and low branching ratios (<1%). Both these obstacles can be remedied by the integration of such systems into Fabry-Pérot microcavities. Here we present the development and testing of a cryo-compatible, high-finesse all-fibre microcavity designed for the purpose of REI spectroscopy. The cavity is largely monolithic in design with a single controllable degree of freedom, which reduces the mechanical noise present in the system (rms = 430 fm at cryogenic temperatures) and therefore allows us to maximise the Purcell-factor. Additionally, high quality (rms ∼1 nm) Eu^{3+} based crystalline organic molecules have been grown onto fibre-end facets, suitable for integration into the cavity.

Q 37.2 Wed 17:00 Tent B

Spatial Confinement of Atomic Excitation by Composite Pulses in Pr:YSO — •Niels Joseph[1], Markus Stabel[1], Nikolay Vitanov[2], and Thomas Halfmann[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Germany — [2]Department of Physics, St. Kliment Ohridski University of Sofia, Bulgaria

We experimentally demonstrate spatial confinement of atomic excitation by narrowband composite pulse sequences in Pr:YSO. In particular, we implement a variety of previously proposed sequences and compare their performance. We achieve population transfer that is spatially confined to an area significantly smaller than the diameter of the driving Gaussian-shaped laser pulses. Our experimental data agree well with a numerical simulation and confirm that the confinement improves with the number of pulses in the sequence. However, we find that inhomogeneous broadening in Pr:YSO reduces the performance, i.e., leading to the formation of additional rings around the localized centre. A theoretical treatment, confirmed by experiments, shows that the perturbing effect can be reduced by carefully choosing experimental parameters. Our experiments prove that narrowband composite pulses are a versatile tool to localize atomic excitation, potentially also below the diffraction limit. This could also be of relevance to quantum computation, as further generalized composite sequences enable arbitrary quantum gate operations in precisely confined spatial regions.

Q 37.3 Wed 17:00 Tent B

Getting topological invariants from snapshots: a protocol for defining and calculating topological invariants of systems with discrete parameter space — •Youjiang Xu and Walter Hofstetter — Goethe-Universität, Institut für Theoretische Physik, Frankfurt am Main, Germany

Topological invariants, including the Chern numbers, can topologically classify parameterized Hamiltonians. We find that topological invariants can be properly defined and calculated even if the parameter space is discrete, which is done by geodesic interpolation in the classifying space. We specifically present the interpolation protocol for the Chern numbers, which can be directly generalized to other topological invariants. The protocol generates a highly efficient algorithm for numerical calculation of the second and higher Chern numbers, by which arbitrary precision can be achieved given the values of the parameterized Hamiltonians on a coarse grid with a fixed resolution in the parameter space. Our findings also open up opportunities to study topology in finite-size systems where the parameter space can be naturally discrete.

Q 37.4 Wed 17:00 Tent B

Dissipative stabilization of molecular rotational states against blackbody radiation and spontaneous decay — •Brandon Furey, Mariano Monsalve, Zhenlin Wu, Stefan Walser, Elyas Mattivi, Rene Nardi, and Philipp Schindler — Universität Innsbruck

Novel quantum information encoding schemes are possible in the rotational degrees of freedom in molecules which are not available in atoms.[1] However, these codes are vulnerable to rotational transitions induced by the environment; namely, blackbody radiation and spontaneous decays. Encoding in a single rotational manifold may enable protection against such decoherence.[2] Theoretically, we are developing a dissipative quantum error correction (QEC) scheme which can be continuously applied to stabilize a rotational superposition.

Experimentally, we aim to demonstrate state preparation, coherent control, and the creation of superpositions of rotational states in CaH^+ or $CaOH^+$ molecular ions using Raman setups with two CW laser beams and another with an optical frequency comb.[3] This could pave the way for exploring QEC codes based on trapped molecular ions.

[1] V. Albert, et al. Phys. Rev. X 10, 031050 (2020)
[2] S. Jain, et al. arXiv:2311.12324 [quant-ph] (2023)
[3] C. Chou, et al. Science 367, 1458 (2020)

Q 37.5 Wed 17:00 Tent B

A versatile algorithm for ion configuration determination in linear ion crystals consisting of mixed atomic and molecular ion species — •Stefan Walser, Brandon Furey, Zhenlin Wu, Rene Nardi, Mariano Isaza Monslave, Elyas Mattivi, and Philipp Schindler — Insitut für Experimentalphysik, Universität Innsbruck

Trapped atomic ions enabled a variety of developments in quantum information and computation in the last two decades. Recently efforts have been made to extend this well studied platform to molecular ions. The latter's additional degrees of freedom might provide a more resource efficient toolkit for quantum computational processes. Therefore, atomic logic ions are co-trapped with molecular ions for sympathetic cooling, state preparation, and readout. Often molecular ions cannot be observed directly but their presence is indicated by vacancies in trapped ion chains. Thus, new methods to rapidly and precisely identify and locate molecular ions are required. We present a featureful algorithm based on a custom peak finder and template fitting which processes image data of the ion crystal. It reliably counts bright logic and dark molecular ions and measures the ion configuration in real time on ms timescales. This provides a versatile basis for automated in-time decision making in various novel experiments.

Q 37.6 Wed 17:00 Tent B

Non-Markovianity of the nonlinear Caldeira-Leggett model — •Moritz F. Richter and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Germany

Employing the simulation method of the hierarchical equations of motion (HEOM), we investigate the nonlinear Caldeira-Legget model, a paradigmatic microscopic system-reservoir model used in open system theory. In particular, we study the impact of a nonlinear coupling of the open system to the reservoir modes on the size of memory effects quantified by the trace distance based measure for non-Markovianity [1]. We also discuss the role of instabilities of the HEOM method and how these influence the numerical determination of the non-Markovianity measure.

[1] Breuer H-P, Laine E-M, Piilo J and Vacchini B; 2016 "Colloquium: non-Markovian dynamics in open quantum systems"; Rev. Mod. Phys. 88 021002

Q 37.7 Wed 17:00 Tent B

Characterization of squeezing sources using Hong-Ou-Mandel interference measurements — •Florian Lütkewitte, Kai Hong Luo, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Gaussian boson sampling (GBS) is a promising platform for demonstrating photonic quantum advantage and noisy intermediate-scale quantum computing. The performance of such systems depends on the ability to produce high-quality single-mode squeezed states. One can produce such states by interfering the two modes of a decorrelated, indistinguishable two-mode squeezed state generated in potassium titanyl phosphate waveguides on a balanced beam splitter. However, one needs to confirm that the generated states reach the qualities required for these highly demanding applications. In this work, we investigate the possibilities and limitations of using Hong-Ou-Mandel interference as a characterization method for these squeezed light sources.

Q 37.8 Wed 17:00 Tent B

Energy level renormalization in strongly coupled open quantum systems — •Alessandra Colla, Florian Hasse, Frederike Doerr, Ulrich Warring, Tobias Schaetz, and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

When a quantum system interacts strongly with a general environment, the interaction energy they share can be of the same magnitude as the expectation value of the bare system Hamiltonian, and can no longer be neglected. Is it then justified to still consider the bare system Hamiltonian as the operator determining the energy levels of the system? If we observe the system while it is coupled to the environment, would we witness signatures of the interaction energy in the system? If so, how? We show that in the case of a simple Jaynes-Cummings model, the energy levels of the two-level system undergo a renormalization due to the strong interaction with the mode, in accordance with our recent proposal for a theory of open system quantum thermodynamics [1]. This energy level shift, which is in general time-dependent, is determined by the coupling strength and by the initial state of the mode (typically its associated temperature). Furthermore, it is experimentally accessible in suitable platforms, and leads to the well known Lamb-shift for zero mode temperature and in the limit of large detuning.

[1] A. Colla and H.-P. Breuer, Phys. Rev. A 105, 052216 (2022).

Q 37.9 Wed 17:00 Tent B

Speeding up Quantum Annealing with coupling to meter — •Mykolas Sveistrys[1], Giovanna Morigi[2], and Christiane P. Koch[1] — [1]Fachbereich Physik and Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Quantum annealing is a quantum computing paradigm with great promise, but also many doubts whether it can produce speedups over classical calculations. To speed up quantum annealing calculations, we introduce a (potentially) dissipative protocol that involves a meter qubit coupled to the qubit array (the system) encoding the annealing problem. The coupling is designed to commute with the system Hamiltonian at all times. Depending on the state of the meter qubit, two mechanisms emerge that result in enhanced adiabaticity and, therefore, a faster time-to-solution: dephasing of the system in its instantaneous eigenbasis, and an effective rescaling of the system's energy levels. We first analyse analytically the conditions where each mechanism dominates, finding that under some circumstances, one should optimize for maximal energy rescaling at the cost of zero dephasing. We then numerically demonstrate the speedup such a protocol yields. We show a 3.6x speedup in time-to-solution on a small-scale instance of the Minimum Weighted Vertex Cover Problem, and a 28% speedup in time-to-solution, seemingly without any dependence on problem size, on a larger benchmark of random Ising models.

Q 37.10 Wed 17:00 Tent B

Quantum Feedback Control for Quantum Error Correction on Superconducting Qubits — •Anton Halaski and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Continuous quantum error correction (QEC) is required in many situations in which the limit of a strong projective measurement cannot be applied. Recently, Atalaya et al. [*Phys. Rev. A* **103**, 042406 (2021)] proposed a continuous QEC scheme for quantum information applications which involve continuously varying Hamiltonians. This scheme relies on a sufficiently strong and continuous two-qubit parity measurement to extract the error syndromes. To implement such a measurement is particularly challenging, since one has to perform a fast, nonlocal measurement while at the same time not introducing any errors to the information encoded in the qubits. We investigate to what extent this task can be accomplished using current circuit QED architecture. Recent proposals for continuous parity measurements in this field rely on the so-called dispersive regime in which the transmons are far detuned from a resonator which acts as the meter for the parity measurement. As a result, transmons and resonator are only weakly coupled and the measurement is slow. We explore how one can achieve speedups by going to the quasi-dispersive regime. Measurements based on the quasi-dispersive regime could then be utilized to enhance the resilience of Atalaya et al.'s and future QEC protocols.

Q 37.11 Wed 17:00 Tent B

Dilute measurement-induced cooling into many-body ground states — •Josias Langbehn[1], Kyrylo Snizhko[2], Igor Gornyi[3], Giovanna Morigi[4], Yuval Gefen[5], and Christiane Koch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Université Grenoble Alpes, Grenoble, France — [3]Karlsruhe Institute of Technology, Karlsruhe, Germany — [4]Saarland University, Saarbrücken, Germany — [5]Weizmann Institute of Science, Rehovot, Israel

Cooling a quantum system to its ground state is important for the characterization of non-trivial interacting systems, and in the context of a variety of quantum information platforms. In principle, this can be achieved by employing measurement-based passive steering protocols, where the steering steps are predetermined and are not based on measurement readouts. However, measurements, i.e., coupling the system to auxiliary quantum degrees of freedom, is rather costly, and protocols in which the number of measurements scales with system size will have limited practical applicability. Here, we identify conditions under which measurement-based cooling protocols can be taken to the dilute limit. For two examples of frustration-free one-dimensional spin chains, we show that steering on a single link is sufficient to cool these systems into their unique ground states. We corroborate our analytical arguments with finite-size numerical simulations and discuss further applications.

Q 37.12 Wed 17:00 Tent B

Suppression of Servo-Phase Noise for High-Fidelity Rydberg Excitations — Philipp Herbig[1], Ben Michaelis[1], Nejira Pintul[1], Tobias Petersen[1], Jonas Rauchfuss[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[1], Till Schacht[1], Alexander Ilin[1], •Koen Sponselee[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Institute for Quantum Physics, Hamburg, Germany

Neutral-atom quantum computers require highly-stable lasers for resonant excitation, which is usually achieved with a Pound-Drever-Hall (PDH) locking scheme. However, this feedback scheme creates servo bumps, which can severely limit excitation fidelities if the servo bandwidth frequency is similar to the Rabi frequency. A feed-forward scheme by Li et al. [1] supresses these servo bumps, and is here implemented in our Ytterbium quantum-computing experiment.

We are setting up our experiment to trap neutral 171-Ytterbium atoms in optical tweezers, providing several options for qubits. A 301.5 nm laser can then be used to excite $^3P_0$ state atoms to an $(n > 50)$ $^3S_1$ Rydberg state, entangling two neighbouring qubits with expected Rabi frequencies on the order of MHz. The fundamental of this laser is first stabilised to a cavity with a PDH lock. The servo bumps, about 500 kHz away from the carrier, are supressed by more than 20 dB using this scheme [1]. Simulations indicate that this method leads to significantly better excitation fidelities.

[1] Li et al., PRA 18, 064005 (2022)

Q 37.13 Wed 17:00 Tent B

Analysis of motional heating during ion-transport through RF junctions in a surface-electrode Paul trap — •Phil Nuschke[1], Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Ger- many — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Ion transport through RF junctions is essential for the scaling of trapped-ion quantum processors in the QCCD architecture. It is crucial to minimise the heating rates during ion transport through an RF junction to avoid excessive overhead in sympathetic re-cooling. This becomes increasingly important the greater the number of qubits, since transport times become a limiting factor. The interplay of transport speed and heating is complex and comprises effects from anomalous heating, pseudopotential gradient heating, non-adabaticities imperfect transport waveform realizations. Here we discuss estimates of pseudopotential gradient heating vs. anomalous heating as a function of transport speed.

Q 37.14 Wed 17:00 Tent B

Fault-Tolerant One-Bit Addition with the Smallest Interesting Colour Code — •Yang Wang[1], Selwyn Simsek[2], and Ben Criger[2] — [1]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany — [2]Quantinuum, Terrington House, 13-15 Hills Road, Cambridge, CB2 1NL, UK

Fault-tolerant operations based on stabilizer codes are the state of the art in suppressing error rates in quantum computations. Most such codes do not permit a straightforward implementation of non-Clifford logical operations, which are necessary to define a universal gate set. As a result, implementations of these operations must either use error-correcting codes with more complicated error correction procedures or gate teleportation and magic states, which are prepared at the logical level, increasing overhead to a degree that precludes near-term implementation. In this work, we implement a small quantum algorithm, one-qubit addition, fault-tolerantly on the Quantinuum H1-1 quantum computer, using the 8-qubit error detection code. By removing unnecessary error-correction circuits and using low-overhead techniques for fault-tolerant preparation and measurement, we reduce the number of error-prone two-qubit gates and measurements to 36. We observe arithmetic errors with a rate of ~ 0.11% for the fault-tolerant circuit and ~ 0.95% for the unencoded circuit.

Q 37.15 Wed 17:00 Tent B

Microwave near-field and stimulated-Raman quantum control of ^{9}Be$^+$ ions in a cryogenic surface-electrode trap — •Emma Vandrey[1], Sebastian Halama[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38166 Braunschweig, Germany

Trapped-ion qubits are a promising hardware platform for quantum computing and quantum simulation. In our group, we employ surface-electrode Paul traps to confine ^{9}Be$^+$ ions and encode the qubits in two hyperfine levels of these ions. For motional ground-state cooling and quantum logic gates, the ability to drive sideband and carrier transitions with frequencies in the microwave regime is required. Integrating microwave conductors into the surface-electrode trap allows the ion's internal and motional states to be controlled using oscillating magnetic fields and an oscillating magnetic gradient.

Alternatively, we can apply stimulated-Raman laser pulses to drive transitions at microwave frequencies. The laser light for this setup is generated via sum-frequency generation and subsequent second harmonic generation. Variable frequency control is implemented using a double-pass acousto-optic modulator setup with a geometry that is inherently stable with respect to thermal effects.

Both of these approaches were implemented in the context of a cryogenic ion trap apparatus. We will report on the status of the project and on a new generation of segmented multi-ion trap chips to be implemented in this environment.

Q 37.16 Wed 17:00 Tent B

Automated modular design of surface electrode Paul traps for quantum computing — •Brigitte Kaune[1], Janina Bätge[1], Axel Hoffmann[1,2], Rodrigo Munoz[1], Florian Ungerechts[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Surface electrode Paul traps with integrated microwave conductors for near-field quantum control are one of the most promising approaches for scalable quantum processors. In the trap design process, numerical simulations using e.g. FEM solvers are crucial. Building the system can be time consuming and slows down the design process. We present progress on a modular trap zone component library for rapid design of multilayer surface electrode Paul traps with integrated microwave conductors. The library is currently being written for automated building with a commercial high-frequency system simulation design software, allowing further pre-definition of excitations and analysis setups to speed up the design process as efficiently as possible.

Q 37.17 Wed 17:00 Tent B

Realization of elementary operations for continuous-variable quantum computers — •Freyja Ullinger, Rudi Pietsch, Alexander Sauer, and Matthias Zimmermann — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Continuous-variable quantum computers encode information and perform calculations based on continuous degrees of freedoms, such as e.g. position or momentum. In this case, the elementary logical gates are characterized by continuous transformations such as displacement, rotation and shearing[1,2]. However, the implementation of these gates is limited to the experimentally available operations to manipulate continuous quantum states. Therefore, it is necessary to develop schemes that are applicable in a variety of physical systems.

In this poster, we present a representation-free theory to realize the displacement, rotation and shearing operator for particles with non-vanishing mass. Our method is solely based on the application of linear and quadratic potentials that either act instantaneously or for a finite period of time, which makes our approach versatile for various continuous quantum systems.

[1] S. L. Braunstein and A. K. Pati, *Quantum Information with Continuous Variables* (Kluwer Academic Publishers, Dordrecht, The Netherlands, 2003).

[2] S. L. Braunstein and P. van Loock, Rev. Mod. Phys. **77**, 513 (2005).

Q 37.18 Wed 17:00 Tent B

QuMIC - Towards a scalable ion trap with integrated high-frequency control — •Marco Bonkowski[1], Sebastian Halama[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Surface-electrode ion traps are a promising candidate for a scalable quantum computer [1]. A major challenge in this approach to quantum computing is the integration of qubit control into the device. With the microwave near-field approach [2], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. The QuMIC project researches and develops novel highly integrated BiCMOS chips at high frequencies and their hybrid integration with quantum electronics like ion traps. This approach enables the scalability of a quantum computer to a large number of qubits and a drastic reduction in the number of required high-frequency lines, which also benefits the cooling capabilities of the cryostat used to cool down the ion trap to around 4K. We describe the setup of a cryogenic ion trap apparatus with the associated laser systems for beryllium. The apparatus will be used as a testing stand for rapid trap testing, such as the ion traps with integrated microwave sources developed for QuMIC. We will report on the current status of the project.

[1] Chiaverini et al., Quantum Inf Comput 5, 419-439 (2005)

[2] Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008)

Q 37.19 Wed 17:00 Tent B

RF junctions for register-based trapped-ion quantum processors — •Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

RF junctions are crucial for scaling trapped-ion quantum processors connecting the specialized zones in the QCCD architecture. We discuss the design and optimization techniques of such an RF junction for a surface-electrode trap, focusing on the implications for through-junction ion transport. We present an optimized RF X-junction feasible for the transport of single ^{9}Be$^+$ ions and multilayer microfabrication.

Q 37.20 Wed 17:00 Tent B

Multiplexing of the transport through an X-junction ion trap — •Janina Bätge[1], Rodrigo Munoz[1], Florian Ungerechts[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz

Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

One of the current problems in scaling up ion trap quantum processors is the large number of control signals. Therefore, concepts to reduce the amount of required signals are needed. We present a concept for multiplexing the control signals for a surface electrode ion trap with an X-junction. One of the key issues is the estimation of the minimum number and the appropriate combination of signals needed for through-junction transport.

Q 37.21 Wed 17:00 Tent B

Optical integration with femto-second laser written waveguides — •Marco Schmauser[1], Philipp Schindler[1], Thomas Monz[1], Marco Valentini[1], Jakob Wahl[1,2], Alexander Zesar[2,3], Klemens Schueppert[2], Bernhard Lamprecht[4], Philipp Hurdax[4], Clemens Rössler[2], and Rainer Blatt[1,5] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Universität Graz, Graz, Austria — [4]Joanneum Research, Weiz, Austria — [5]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Austria

Current ion trap quantum computing systems usually make use of free-space optics to deliver the light to the ions. This practice makes the setups susceptible to drifts and vibrations and limits the number of ions which can be manipulated. For a scalable system it is thus necessary to increasingly integrate optical elements from external components directly into the ion trap.

We use femto-second laser pulses to write single-mode and polarization-maintaining waveguides directly into borofloat glass. Unlike other materials used in CMOS technology, borofloat glass is transparent for ultraviolet light required for the manipulation of 40Ca+ ions. Henceforth, a microstructured surface trap was realized featuring two of these waveguides, one for 397nm light and one for 729nm light. In parallel, we build up an integrated cryogenic quantum computing system to enable fast trap testing and to investigate the quality of the light delivery to the ions.

Q 37.22 Wed 17:00 Tent B

Building a tweezer array with programmable connectivity — •Johannes Schabbauer, Stephan Roschinski, Marvin Holten, and Julian Léonard — TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), 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 present a novel platform to engineer non-local interactions between single atoms in optical tweezers by strong coupling to an optical cavity. In our experiment we use a fiber cavity, which enables good optical access for placing high resolution microscopes above and below the cavity. These microscopes are used for creating the tweezer array, single-site resolved imaging, and addressing single atoms in the 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 37.23 Wed 17:00 Tent B

Coherent control of strontium atoms trapped in an optical lattice and applications for quantum simulations — •Jan Geiger[1,2], Valentin Klüsener[1,2], Sebastian Pucher[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Neutral atoms trapped in optical lattices allow for precise measurements, quantum simulation, and quantum computation. Here, we demonstrate the essential building blocks for a quantum simulator: state-dependent trapping, large, homogeneous optical lattices, single-atom resolved fluorescence imaging, and high-resolution optical spectroscopy. We present the first coherent excitation of the ultranarrow $^1S_0$-$^3P_2$ magnetic quadrupole transition in ^{88}Sr. Building on this work, we demonstrate high-fidelity Rabi oscillations between the $^3P_0$ and $^3P_2$ state. The developed spectroscopy methods enable us to perform quantum simulations on strongly coupled light-matter interfaces.

Q 37.24 Wed 17:00 Tent B

Quantum speed limit dependence on the number of controls in a qubit array — •David Pohl, Fernando Gago-Encinas, Matthias Krauss, and Christiane P. Koch — Arnimallee 14, 14195 Berlin

Universal quantum computing requires operator controllability of the qubit array. This is typically realized via qubit-qubit couplings and local external controls on every qubit which becomes challenging when scaling to large numbers of qubits. We have shown recently that the number of external controls can be reduced to the extreme limit of a single control. However, this comes at the expense of longer gate durations. Here, we investigate the gate duration depending on the number of local controls. In particular, we show that reducing controls increases the quantum speed limit (the shortest time to generate a quantum gate). We determine this limit for a universal set of gates for different 3-qubit systems using quantum optimal control.

Q 37.25 Wed 17:00 Tent B

Realising fast readout for Rydberg arrays — •Balázs Dura-Kovács[1,2], Mehmet Öncü[1,2], Jacopo De Santis[1,2], Sebastian Ruffert[1,2], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Ordered arrays of neutral atoms provide an appealing platform for quantum simulation and quantum computation. Laser-cooled atomic gases allow for simulating quantum many-body systems with unprecedented control over microscopic degrees of freedom. The recent progress on tweezer-based atom arrays and quantum gas microscopes has enabled microscopic detection and manipulation of such systems down to the level of single atoms. Here, we present our progress on an experimental platform aimed at achieving cavity-assisted, nondestructive, local readout of atoms in a tweezer array. Long-range and tunable interactions between highly-excited Rydberg states make the platform suited to simulate spin models and – together with the fast cavity-based readout – form the architectural basis for the realisation of a scalable quantum computing platform.

Q 37.26 Wed 17:00 Tent B

Optical tweezers for trapped ion quantum simulation — •Rima X. Schüssler, Matteo Mazzanti, Clara Robalo Pereira, Nella Diepeveen, Louis Gallagher, Zeger Ackerman, Arghavan Safavi-Naini, and Rene Gerritsma — University of Amsterdam, Amsterdam, The Netherlands

Trapped ion crystals offer an advanced platform for quantum computation and simulation. However, limited control over the interactions between the ions constrains the range of accessible Hamiltonians.

In our experiment, we plan to combine trapped ions with microtraps in the form of optical tweezers. These additional potentials will allow us to manipulate the phonon mode spectrum and thereby control the spin-spin interactions of the ions in a Paul trap. We will use a high power 1030nm laser far detuned from any transition in Yb^+. The tweezers will be produced by a spatial light modulator and focused on the ions to a waist of a few μm with a high NA objective. With the right tweezer pattern [1], we can then use the system to study various Hamiltonians of interest, for example, Hamiltonians on a kagome lattice in 2D ion crystals.

[1] J.D. Espinoza, M. Mazzanti, K. Fouka, R.X. Schüssler, Z. Wu, P.Corboz Phys. Rev. A 104, 013302 (2021).

Q 37.27 Wed 17:00 Tent B

Progress towards a fault tolerant microwave-driven two qubit quantum processor — •Hardik Mendpara[1,2], Nicolas Pulido-Mateo[1,2], Markus Duwe[1,2], Alexander Onkes[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

A universal quantum gate set can be realized by the combination of single-qubit gates and one entangling operation. Here, we realize such a universal gate-set using the microwave near-field approach [1]. We trap $^9Be^+$ ions in a surface electrode trap and perform the quantum logic operations with embedded electrodes. The individual qubits are addressed by micromotion sidebands [2] and the entangling gate is performed via a Mølmer-Sørensen type interaction. We approach an infidelity of 10^{-3} with entangling gates using partial state tomography and in a computational context we extract a composite process infidelity of $3.4(4) \times 10^{-2}$ using the cycle benchmarking protocol [4]. We report on recent progress on improving the gate fidelities and characterizing the quantum process errors.

[1] C. Ospelkaus *et al.*, Phys. Rev. Lett. **9**, 090502 (2008)
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)
[4] N. Pulido-Mateo *et al.*, Manuscript in preparation

Q 37.28 Wed 17:00 Tent B

Employing continuous quantum systems to solve optimization problems — •Alexander Sauer, Sebastian Luhn, and Jannes Weghake — DLR e.V., Institut für Quantentechnologien, Ulm

At land, sea and in the air mobility and traffic management offer a vast amount of problems with a large potential of optimization with quantum computers, e.g. service scheduling, route planning, or path optimization. Many of these problems can be described at a fundamental level by the traveling salesman problem (TSP), in which the shortest route while visiting each point exactly once is to be found [1]. The TSP has already received a lot of attention in the quantum computing community, for example, implementations for adiabatic quantum annealers exist and have been tested [2,3]. We investigate the TSP with a focus on going beyond qubits by employing continuous quantum systems. Using bosonic Qiskit we simulate potential algorithms for solving the TSP and compare their performance.

[1] Flood, M. M., The traveling-salesman problem. Operations research, 4(1), 61-75, (1956).
[2] Martoňák, Roman, Giuseppe E. Santoro, and Erio Tosatti., Quantum annealing of the traveling-salesman problem. Physical Review E 70.5: 057701, (2004).
[3] Jain, S., Solving the traveling salesman problem on the d-wave quantum computer. Frontiers in Physics, 646, (2021).

Q 37.29 Wed 17:00 Tent B

Extreme power spectre effects with special pulse shapes: Power narrowing and power broadening — •Ivo Mihov — Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

The effects of the excitation pulse shape on the transition line of the qubit are detrimental. Some pulse shapes are known to exhibit power broadening (the Rabi model). Others do not depend on the Rabi frequency whatsoever (the Rosen-Zener model). We have even shown that a family of pulse shapes reverse the power broadening effect and exhibits power narrowing instead. They have been theoretically and experimentally demonstrated using IBM Quantum hardware.

In this work we focus on pulse shapes that produce a case of extreme power broadening patterns. They are usually made of a convex shape that starts and ends with a sharp discontinuity, similar to the rectangular pulse shape. The two pulse shapes that were used throughout the experiment were of the form $\Omega_1(t) = \Omega_0 t^{2N}$, where N is a non-negative integer, and $\Omega_2(t) = \Omega_0(1 + \beta t^2)$, where β can be any real number (may also be negative). We have experimentally shown an increase in the 9pi excitation maximum of our custom pulse by a factor of approximately 5 over the one with the simple rectangular pulse using IBM Quantum system ibmq_manila.

Q 37.30 Wed 17:00 Tent B

Entanglement generation in photonic two photon quantum walks — •Federico Pegoraro, Philip Held, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany

Entanglement constitutes a fundamental property for the development of quantum algorithms and protocols capable of outperforming their classical counterparts in terms of speed and resource efficiency. In order to be able to exploit the advantages offered by entanglement one must be capable of producing such a resource. For this reason we study how to generate entanglement in a photonic setting using a well known quantum process: the multi-walker quantum walk (QW). In this process a number of quantum objects, the "walkers", evolve in a position space according to the update of an internal degree of freedom called coin. We use a photon pair produced via type-II spontaneous parametric down-conversion as walkers: their coins are encoded into the respective polarization states, while for the position space we employ a time-multiplexing loop where a given arrival time corresponds to a certain output position. The two photons are launched in the QW and propagate in the setup for a certain amount of roundtrips after which they are released and detected. By performing joint polarization-tomography on the walkers at the output of the QW, we can evaluate the dynamics of entanglement creation and distribution in the QW.

Q 37.31 Wed 17:00 Tent B

Development of time-multiplexed fiber-based quantum walks — •Moritz Borchardt, Federico Pegoraro, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

The random walk stands as a powerful tool within the realm of computer science. Its quantum mechanical counterpart, referred to as the quantum walk, opens up avenues for developing even more efficient algorithms tailored to address both current and future (quantum) computing challenges. Among various possibilities, photonic based implementations have proven to be advantageous in terms of resources needed to realize the quantum walk evolution. Due to complex alignment procedures and large system size, opting for partial integration seems to be a reasonable approach in terms of scaling. Additionally, recent results highlight that achieving the necessary modulation speed, crucial for effective quantum computing, is only feasible through the use of integrated modulators. In fact, integrated thin-film lithium niobate modulators have shown bandwidths in excess of 100 GHz. Here we take a step in this direction and present an implementation of an integrated time-multiplexed quantum walk that relies only on fiber loops and directional couplers. We experimentally demonstrate the quantum walk dynamics, and we investigate effects of unbalanced losses in the setup with an outlook on dynamic implementations requiring fiber based active components that would have an impact on the system efficiency.

Q 37.32 Wed 17:00 Tent B

Quantum Information Processing with trapped-ion based Qudits — •Lukas Gerster[1], Peter Tirler[1], Manuel John[1], Lisa Parigger[1], Michael Meth[1], Claire Edmunds[1], Pavel Hrmo[1], Benjamin Wilhelm[1], Martin van Mourik[1], Rainer Blatt[1,2,3], Philipp Schindler[1], Thomas Monz[1,3], and Martin Ringbauer[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25/4, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria — [3]AQT, Technikerstraße 17, 6020 Innsbruck, Austria

Quantum Information Processing has been predominantly developed using qubits, two level quantum systems, as its fundamental building blocks. However many physical implementations of qubit-based quantum processors actually use multilevel systems, from which only two levels are selected for information encoding. By extending the encoding information in multi-level qudit basis states, one directly expands the Hilbert space available for computation, and promises more efficient compilation with respect to the number of required entangling gates. We experimentally demonstrate an implementation of a native two-qudit entangling gate up to dimension 5 in a trapped-ion system, and we present a new experimental apparatus dedicated for exploring higher dimensional qudit protocols and algorithms up to qudit dimension d=7.

Q 37.33 Wed 17:00 Tent B

Gerchberg-Saxton Algorithm for Optical Tweezer Arrays — •Jonas Rauchfuss[1], Nejira Pintul[1], Tobias Petersen[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[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

Neutral atoms have shown to be a promising candidate for building large scale quantum computing devices, with fast high-fidelity single and two-qubit gates as well as flexible initialisation and readout. Recently, alkaline earth (-like) atoms such as ytterbium (Yb) and strontium (Sr) have shown to offer promising ways to overcome some of the main challenges on the road to large scale, fully programmable quantum computers with decent effective circuit depth. In this context, uniformly trapping atoms within optical tweezers is crucial for ensuring prolonged coherence times and mitigating qubit dephasing. This poster focuses on the implementation of two distinct variations of the Gerchberg-Saxton algoritm (GSA) utilized for generating and homogenising optical tweezer arrays using a spatial light modulator (SLM). Moreover, we implemented a camera feedback into our system to improve optimization and responsiveness. Our analysis compares the efficacy of these approaches in creating intermediate-scale, uniform optical tweezer arrays.

Q 37.34 Wed 17:00 Tent B

Gerchberg-Saxton Algorithm for Optical Tweezer Arrays — •Jonas Rauchfuss[1], Nejira Pintul[1], Tobias Petersen[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[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

Neutral atoms have shown to be a promising candidate for building large scale quantum computing devices, with fast, high-fidelity single and two-qubit gates as well as flexible initialisation and readout. Recently, alkaline earth (-like) atoms such as ytterbium (Yb) and strontium (Sr) have shown to offer promising ways to overcome some of the main challenges on the road to large scale, fully programmable quantum computers with decent effective circuit depth. In this context, uniform trapping of atoms within optical tweezers is crucial for ensuring prolonged coherence times and mitigating qubit dephasing. This poster focuses on the implementation of two distinct variations of the Gerchberg-Saxton algorithm (GSA) utilized for generating and homogenising optical tweezer arrays using a spatial light modulator (SLM). Moreover, we implemented a camera feedback into our system to improve optimization and responsiveness. Our analysis compares the efficacy of these approaches in creating intermediate-scale, uniform optical tweezer arrays.

Q 37.35 Wed 17:00 Tent B

Solving optimization problems with local light shift encoding on Rydberg quantum annealers — •Kapil Goswami[1], Rick Mukherjee[1], Herwig Ott[2], and Peter Schmelcher[1] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Department of Physics and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau,67663 Kaiserslautern, Germany

The current era of quantum computers is characterized by a limited number of qubits, high levels of noise, and imperfect quantum gates. Despite these limitations, neutral atom analog quantum computers offer opportunities for exploring the potential advantages. We provide an efficient framework to solve combinatorial optimization problems such as Maximum Cut (Max-Cut) and Maximum Independent Set (MIS) on a Rydberg quantum annealer. Our system employs locally controlled light shifts on individual qubits in a many-body Rydberg setup, mapping graph problems to the Ising spin model. Using optimal control methods, our numerical simulations implement the local-detuning protocol while globally driving the Rydberg annealer to the desired many-body ground state, which is the solution to the optimization problem. The solutions are obtained for prototype graphs with varying sizes at time scales well within the system lifetime and with approximation ratios close to one. A comparative analysis with classical simulated annealing is provided which highlights the advantages of our scheme in terms of system size, hardness of the graph, and the number of iterations required to converge to the solution.

Q 37.36 Wed 17:00 Tent B

Quantum gas microscopy of strongly correlated states of the Fermi-Hubbard model — •Johannes Obermeyer[1], Dominik Bourgund[1], Petar Bojovic[1], Si Wang[1], Titus Franz[1], Thomas Chalopin[1], Immanuel Bloch[1,2], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, München, Germany

The Fermi-Hubbard model describes phenomena in condensed matter physics including strange metals, the pseudogap or the formation of stripes. The model possibly even explains the fundamental mechanisms of high-Tc superconductivity. With our quantum gas microscope based on ultracold Li-6 atoms we are able to prepare states of the two-dimensional Fermi-Hubbard model and probe the system with single site spin and density resolution. We use an optical superlattice to engineer the Hamiltonian to a one, two or mixed dimensional system. On top of our optical lattice a potential landscape gets projected by a digital mirror device that facilitates the control of the hole doping in the Fermi-Hubbard system. We present our observations of holes moving in an antiferromagnetic background. These observations mark the onset of exploring antiferromagnetism and the highly anticipated pseudogap phase of the doped Fermi-Hubbard model. In future experiments, we want to explore more fundamental predictions of the Fermi-Hubbard model like Mott excitons and aim to decrease our system temperature exerting bilayer cooling. Additionally, the double well structure of the superlattice is expected to enable the realization of collisional two-qubit gates for digital quantum computing.

Q 37.37 Wed 17:00 Tent B

Quantum Computation with Neutral Alkaline-Earth-like Ytterbium Rydberg Atoms in Optical Tweezer Arrays — •Nejira Pintul[1,2], Tobias Petersen[1,2], Nicolas Heimann[1,2], Lukas Broers[1,2,3], Koen Sponselee[1,2], Alexander Ilin[1,2], Jonas Rauchfuss[1,2], Oscar Murzewitz[1,2], Clara Schellong[1,2], Jan Deppe[1,2], Christoph Becker[1,2], Ludwig Mathey[1,2,3], and Klaus Sengstock[1,2,3] — [1]Zentrum für optische Quantentechnologien, 22761 Hamburg — [2]Institut für Quantenphysik, 22761 Hamburg — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Arrays of neutral atoms have evolved into a leading platform for quantum computation. Alkaline-earth-like atoms promise to overcome present limitations imposed on fault-tolerant quantum computation with its two valence electron structure and single-photon Rydberg transitions, enabling new error correction schemes [1], mid-circuit readout [2-4] and novel qubit architectures [5]. Here we present our experimental approach to building an ytterbium-based Rydberg tweezer experiment and report on the recent realization of uniform tweezer arrays as well as mobile traps for atom reconfiguration. We present a machine learning assisted two-qubit gate design [6] utilizing a hybrid-classical optimizer to construct fidelity-optimal pulse sequences for realizing CNOT gates, while assuming feasible experimental parameters. [1] Nat Commun 13, 4657 (2022) [2] Nature 622, 279284 (2023) [3] PRX Quantum 4, 030337 (2023) [4] Phys. Rev. X 13, 041035 (2023) [5] Phys. Rev. A 105, 052438 (2022) [6] arXiv 2306.08691

Q 37.38 Wed 17:00 Tent B

Optical Protocol for Generating Squeezed Coherent State Superpositions — •Elnaz Bazzazi, Roger Alfredo Kögler, Leon Reichgardt, and Oliver Benson — Department of Physics, Humboldt University Berlin, Berlin, Germany

Non-Gaussian states play a crucial role in fault-tolerant quantum computing, where the manipulation of quantum states is susceptible to errors [1]. Certain classes of non-Gaussian states, notably coherent state superpositions known as cat states, pose challenges in generation due to complexity of breeding protocols and limitations in their output state [2,3]. In this study, we explore an extension of the protocol proposed in ref [4] that makes use of squeezed states and photon number-resolving detectors as resources, demonstrating potential in generating high-amplitude squeezed cat states. Simulation results validate the efficacy of this protocol, and we suggest an experimental setup for its practical realization. This research contributes to advances in fault-tolerant quantum information processing through the generation of non-Gaussian states.

[1] Phys. Rev. A 106, 022431 (2022).
[2] Phys. Rev. A 103, 013710 (2021).
[3] Opt. Express 31, 12865-12879 (2023).
[4] Phys. Scr. 97 115002 (2022).

Q 37.39 Wed 17:00 Tent B

Towards time-bin entangled photon cluster states — •Siavash Qodratipour, Thomas Häffner, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, Berlin, Germany

Single photons are ideal carriers of quantum information due to the lack of interaction with each other. However, manipulating and controlling them for quantum computing becomes a difficult task. One-way quantum computation [1] overcomes this challenge by avoiding non-linear two-qubit interaction and instead uses highly entangled states called ”cluster states”. Together with single qubit measurements and feed-forward a scalable universal quantum computer can be implemented [2]. The aim of our research is to realize a cluster state by fusion of few photon qubits which are time-bin encoded (early and late time-bins) in optical fibres. In this presentation, we will report on the generation of time-bin entangled photon pairs at 1560 nm and the subsequent characterization of the energy-time and time-bin entanglement by two photon interference [3]. We will also outline how we implement interferometric phase stability and arbitrary phase point control which are necessary to achieve a reproducible and deterministic interference. Scalability of our approach will be discussed as well.

References:
[1] Raussendorf, R. et al. Phys. Rev. Lett. 86, 5188-5191. (2001).
[2] Lu, CY. et al. Nature Phys 3, 91-95 (2007).
[3] Tanzilli, S. et al. Eur.Phys. J. D 18, 155-160 (2002).

Q 37.40 Wed 17:00 Tent B

Towards a quantum gas microscope with programmable lattices — •Sarah Waddington, Isabelle Safa, Marvin Holten, and Julian Léonard — Atominstitut TU Wien, Vienna, Austria

Cold atoms in optical lattices are a powerful platform for investigating and simulating a wide range of physical phenomena relevant to areas from condensed matter to quantum information. Our poster will describe the ongoing design and development of a quantum gas microscope capable of operation with Li6 (fermionic) or Li7 (bosonic) in a reconfigurable lattice potential with site-resolved state preparation, evolution, and readout. The setup is optimized to reach sub-second cycle times by removing the transport step and implementing advanced cooling techniques.

Potential avenues of research for our new project include simulating and investigating phases of matter predicted by the Fermi-Hubbard model, fractional quantum Hall phases, and 'frustrated' systems with unconventional lattice shapes.

Q 37.41 Wed 17:00 Tent B

Optical Ising model simulations with caesium vapor cells — •Kilian Junicke[1], Elizabeth Robertson[1,2], Mingwei Yang[1,2], Inna Kwiatkowski[2,3], and Janik Wolters[1,2] — [1]Technische Universität Berlin, Institute for Optics and Atomic Physics, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Rutherfordstr. 2, 12489 Berlin, Germany — [3]TU Berlin, Institut für Luft und Raumfahrt

Several computationally hard optimization problems can be mapped to finding the ground state of an Ising model [1]. Simulating Ising models optically promises speed increases [2]. Building an optical Ising machine then raises the question of how to simulate the spin states [3].

Here we present a scheme for simulating an Ising model using the ground states of cesium vapor at room temperature. We present methods for implementing positive and negative interactions using a measurement and feedback strategy. In the system electromagnetically induced transparency acts as a frequency transducer. We initialize the system and allow it to evolve by executing a series of pump probe operations on spatially multiplexed regions of an atomic vapor cell until a ground state solution is found.

[1] Lucas, A. Ising formulations of NP problems. Front. Phys. 2, 5 (2014).
[2] McMahon, P.L. Physics of optical computing. Nat Rev Phys 5, 717-734 (2023).
[3] Böhm et al. Poor man's coherent Ising machine for optimization. Nat Commun 10, 3538 (2019).

Q 37.42 Wed 17:00 Tent B

Graph states generation from one and two atoms in an optical cavity — Philip Thomas, •Leonardo Ruscio, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

Given the importance of multiphoton graph states in quantum computation and communication, their experimental demonstration is an important step towards the realization of e.g measurement based quantum computation. In our work we used single rubidium atoms trapped in the center of a Fabry-Perot cavity to grow photonic graph states. With a single atom we implemented a deterministic protocol to efficiently generate Greenberger-Horne-Zeilinger (GHZ) states and linear cluster states up to 14 and 12 photons respectively, with fidelity greater than of 76(6)% and 56(4)% [1]. Thanks to an overall single photon efficiency of 43% we collected these large states at a rate of about one coincidence per minute. Using two atoms we demonstrated the generation of more complex graphs, such as tree and ring states, exploiting an entangling mechanism based on the simultaneous emission and subsequent interference of two photons in the cavity mode [2]. Starting with two independent GHZ states we produced a tree composed of eight qubits with a lower bound fidelity of 69%. Furthermore, fusing a linear cluster states with two entangling operations we also obtained rings of six and eight qubits.

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

Q 37.43 Wed 17:00 Tent B

Exploring the stability and performance of integrated linear optical networks for photonic quantum computing — •Cheeranjiv Pandey, Federico Pegoraro, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

In recent years, photonic quantum computing has emerged as a highly promising platform. This is particularly evident in the context of demonstrating quantum advantage in noisy intermediate-scale quantum (NISQ) computing, as explored in tasks like Boson Sampling. However, the success of many such computations relies on the ability to accurately implement arbitrary unitary transformations on input quantum states. Previous work has demonstrated the feasibility of implementing arbitrary unitary transformations using an array of linear optical elements, such as beam splitters and phase shifters. This insight led to the conceptualization of a multi-port interferometer, a versatile network that can be programmed for implementing any unitary transformation between input and output channels. The accuracy and stability of these transformations on multi-port interferometers is crucial for effective quantum algorithms. Our ongoing research explores the stability and performance of programmed unitary operations in commercially available multi-port interferometers, with the aim to investigate their suitability for photonic quantum computing.

Q 37.44 Wed 17:00 Tent B

Ion trap architectures for enhanced qubit connectivity — •Marco Valentini[1], Martin van Mourik[1], Friederike Butt[4], Matthias Dietl[1,2], Jakob Wahl[1,2], Michael Pfeifer[1,2], Marco Schmauser[1], Bassem Badawi[1], Philip Holz[3], Clemens Rössler[2], Markus Müller[4], Thomas Monz[1,3], Philipp Schindler[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Alpine Quantum Technologies GmbH, 6020 Innsbruck, Austria — [4]Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

We investigate scalable ion trap architectures for quantum computing, where independent ion strings are located in distinct lattice sites (or potential wells) in a 2D array of RF traps. Distinct ion strings are coupled via their dipole-dipole interaction. Full 2D connectivity is achieved tuning the distance between adjacent potential wells along two orthogonal directions: One direction (axial) is achieved controlling DC voltages, and the other (radial) controlling RF fields. In this work we demonstrate the building blocks of such an architecture using two surface ion traps. With the first, we demonstrate DC shuttling-based well-to-well coupling rates up to 40 kHz, and phonon exchange between ion strings at the quantum level. With the second, we characterize transport of ions along the radial direction, and measure well-to-well coupling rates up to 15 kHz. These results provide an important insight into the implementation of fully controllable 2D ion trap lattices, and pave the way to the realization of 2D logical encoding of qubits.

Q 37.45 Wed 17:00 Tent B

A quantum key distribution network with a multi-user phase-time coding quantum key hub for city-wide deployment — •Maximilian Tippmann, Florian Niederschuh, Erik Fitzke, Till Dolejsky, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

Today's IT infrastructure is threatened e.g. by quantum computers implementing Shor's algorithm. Quantum key distribution (QKD) offers a method to make this infrastructure resilient against such future attacks. While various QKD setups have been tested relying on numerous different protocols, most systems do not consider scaling beyond more than two users. We report on a phase-time coding protocol based quantum key hub. The star-shaped layout of our network with an entangled photon pair source as a central untrusted node allows scaling to more than 100 users. We demonstrate the feasibility of a city-wide network by showing results from experiments with parties spatially distributed in separate buildings connected via field-deployed fiber. During a measurement our system is able to generate real-time secure keys, with one of two implemented error-correction algorithms. Furthermore, we demonstrate the plug-and-play flexibility and robustness of our setup allowing for different fiber distances, connected parties and long-time operation over several hours.

Q 37.46 Wed 17:00 Tent B

Coupling of photonic crystal fibers to nonlinear waveguides for quantum frequency conversion — •Felix Rohe, Marlon Schäfer, Tobias Bauer, David Lindler, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Quantum frequency conversion to the low-loss telecom bands is a key enabling technology for long-range fiber-based quantum networks. While many current devices use free space coupling to channel waveguides [1,2], for real world applications a more robust and compact design is desirable. Hence, direct butt-coupling of optical fibers to channel waveguides poses an interesting alternative.
Here, we investigate coupling of solid-core photonic crystal fibers (PCF) to periodically poled lithium niobate waveguides. PCF are promising candidates for use in quantum frequency conversion due to their ability to simultaneously guide waves with a large difference in wavelengths in the fundamental mode, which is crucial to spatially overlap the signal photons and the mixing wave. We show first results regarding coupling and conversion efficiencies.

[1] Bock, M. et al., Nat Commun 9, 1998 (2018)
[2] Schäfer, M. et al., Adv Quantum Technol. 2023, 2300228

Q 37.47 Wed 17:00 Tent B

From Nonlinear Frequency Conversion towards Quantum Frequency Conversion — Anica Hamer[1], •Priyanka Yashwantrao[1], Alireza Aghababaei[1], Frank Vewinger[2], and Simon Stellmer[1] — [1]Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany — [2]Institut für Angewandte Physik, Wegelerstraße 8, Universität Bonn

Quantum networks, as envisioned for quantum computation and quantum communication applications, are often based on a hybrid architecture. Such a layout may include solid-state emitters, network nodes based on single or few atoms or ions, and photons as so-called flying qubits. This approach requires an efficient and entanglement-preserving exchange of photons between the individual components and so involves frequency conversion of the photon.

We have established two different platforms to convert individual photons between wavelengths that are relevant for qubit platforms.

The first platform is based on nonlinear crystals and converts photons from 853 nm (InAs/GaAs QDs) to 370 nm (Yb^+ ions).

The second platform is based on CSRS and CARS in dense molecular hydrogen gas. We have demonstrated conversion between 434 nm (F donors in ZnSe) to 370nm (Yb^+ ions) and between 863 nm (InAs/GaAs QDs) and the telecom O-band. We will present first steps towards integrated frequency conversion in gas-filled hollow-core fibers.

Q 37.48 Wed 17:00 Tent B

PIC based Entangled Photon Pair Source using Spontaneous Four-Wave-Mixing and Pulsed PDH-Locking — •Maximilian Mengler, Jakob Kaltwasser, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

For many applications, such as quantum key distribution (QKD), entangled photon pairs are a necessity. We use the process of spontaneous four-wave-mixing to create these pairs within microring resonators on silicon nitride photonic integrated circuits (PICs). Results regarding, e.g. pair generation rate and coincidental-over-accidental ratio obtained from two distinct PICs with different layouts, specifications, and waveguide geometries will be presented and compared. As the PICs are intended as sources for our time-bin based QKD-system, the PDH technique used to lock the microring resonators to the pump light was adapted for operation with pulsed light.

Q 37.49 Wed 17:00 Tent B

High-performance imaging of nanophotonic structures in cryogenic envoirment — •Timo Eikelmann[1], Donika Imeri[1,2], Rikhav Shah[1], Lasse Irrgang[1], Mara Brinkmann[1], Tuncay Ulas[1], Konstantin Beck[1], Lennart Manthey[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Quantum networks require long coherence times, good interaction between atoms and photons, and strong interaction between qubits. Silicon vacancy centers within a nanophotonic diamond cavity are promising in this field. These nanophotonic structures are essential for light-matter interaction and efficient coupling to the silicon center. Structures are approximately 10 micrometers long and 500 nm wide and placed inside a cryostat to cool them down to around 0.1 Kelvin. Creating a high-performance imaging system inside a cryostat poses challenges. The imaging system must be placed partially inside the cryostat and partially outside and therefore is over 2 meters long. We implement an 8f imaging system and a pair of galvanometer-driven mirrors to scan a focused laser beam across the nanophotonic structure. This enables high-performance imaging, the scanning of a desired area with a laser in a short time and provides flexibility in imaging the given structures. High-resolution imaging enables precise coupling between nanophotonic structures and optical fibers, enabling research of efficient fiber-coupled quantum network nodes.

Q 37.50 Wed 17:00 Tent B

An improved DM-CV-QKD system for metropolitan fiber links — •Stefan Richter[1,2], Hüseyin Vural[1,2], Jan Schreck[1,2], Kevin Jaksch[1,2], Ömer Bayraktar[1,2], Thomas Dirmeier[1,2], Wenjia Elser[1,2], Dominique Elser[1,2], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Max-Planck-Institut für die Physik des Lichts, 91052 Erlangen, Germany

Continuous-variable quantum key distribution (CV-QKD) is a key building block for the quantum-safe encryption schemes needed to protect sensitive communications against the growing threat of many-qubit quantum computers in the coming decades. We present our prototype of a CV-QKD system for metropolitan fiber optical links based on the discrete modulation (DM) of coherent states and compare it to an earlier iteration. We propose solutions to several technical challenges of the implementation, including procedures for automatic working-point stabilization, calibration, as well as phase recovery and tracking. Asymptotic keyrate estimates as a performance metric are discussed in the context of additional constraints imposed by the error correction implemention.

Q 37.51 Wed 17:00 Tent B

Towards Quantum Memories in Noble-Gas Nuclear Spins with Alkali Metal Vapour as Optical Interface — •Norman Vincenz Ewald[1,2], Tianhao Liu[2,5], Alexander Erl[1,2], Luisa Esguerra[1,3], Wolfgang Kilian[2], Jens Voigt[2], Denis Uhland[4], Ilja Gerhardt[4], and Janik Wolters[1,3] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [4]Leibniz University Hannover, Institute of Solid State Physics, Hannover — [5]Tragically deceased on 22 July 2023.

Quantum memories with storage times well beyond 1 s will spawn manifold applications in quantum communication, e.g. as quantum token for authentication. We present our first steps towards a quantum memory with long storage time in a mixture of the noble gas ^{129}Xe and an alkali metal vapour of ^{133}Cs. A custom glass cell at about room temperature contains both species and is placed inside a table-top magnetic shield. Information will be stored in the collective excitation of nuclear spins of ^{129}Xe, which exhibit hours-long coherence times [1]. ^{133}Cs serves as optical interface for signal photons, which we store in a collective spin excitation using EIT [2]. Coherent information transfer to the noble gas spins is based on spin-exchange collisions and will be controlled by synchronisation of Larmor precession [3].
[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010). [2] L. Esguerra et al., *Phys. Rev. A* **107**, 042607 (2023). [3] O. Katz et al., *Phys. Rev. A* **105**, 042606 (2022).

Q 37.52 Wed 17:00 Tent B

Simulation of Cluster state generation process with time-bin protocol — Ruolin Guan[1], •Fei Ding[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany

The on-demand generation of multi-entangled photons is an attractive goal for the realization of quantum communication networks. Photonic Cluster State, is a promising multi-entangled state because they are specifically prepared for measurement-based quantum computation. Here, we propose to develop a simulation method for generating multi-photon states, particularly linear cluster states with time-bin protocol. Additionally, we utilize a local measurement approach to simulate the measurement process.

Q 37.53 Wed 17:00 Tent B

Multiphoton interference in multidimensional systems — •Felix Twisden, Jan Sperling, and Polina Sharapova — Paderborn University, Warburger Strasse 100, 33098 Paderborn

Multidimensional entanglement is a key source for many quantum applications, such as quantum computing, quantum communication and quantum simulation [1]. Therefore, we investigate in this work a four-channeled quantum optical system, which is driven by two spontaneous parametric down-conversion (SPDC) sources (each emitting two photons), in order to characterize the photons via coincidence probability. The system represents an integrated quantum circuit with four channels, based on the platform material lithium niobate. The optical components can be adjusted in such a way that the polarization of the photons can be set individually. Furthermore, a time delay between the four photons can be introduced. In this system, two photon pairs (four photons) are generated by an independent SPDC-source and is therefore characterized by a spectrally entangled frequency distribution. The main goal is to investigate the coincidence probability for the described four photon case of the multichannel and multifrequency system regarding different configurations of the optical elements.

[1] J. Wang, S. Paesani, Y. Ding, R. Santagati, P. Skrzypczyk, A. Salavrakos, J. Tura, R.Augusiak, L. Mančinska, D. Bacco, et al., Multidimensional quantum entanglementwith large-scale integrated optics, Science360, 285*291 (2018).

Q 37.54 Wed 17:00 Tent B

Photonic integrated circuits for phase-encoded prepare-and-measure QKD on a CubeSat — •Joost Vermeer[1,2], Jonas Pudelko[1,2], Kevin Günthner[1,2], and Christoph Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

In the past decade several projects have been started to develop satellite based quantum key distribution (QKD) systems and avoid the range limitations of fiber based QKD systems. The cost of these systems is for a large part determined by the size, weight and power of the satellite. With photonic integrated circuits (PICs) one can integrate many optical components on a single chip, which opens up the possibility to implement all the optical functions necessary for QKD with reduced size, weight and power requirements.

In this work, we will present our optical CubeSat payload for the QUBE-II mission. It will perform phase encoded prepare-and-measure QKD with weak coherent states using an Indium-Phosphide transmitter PIC. We discuss the requirements for this transmitter PIC and compare different PIC design approaches to investigate which one can best fulfill these requirements.

Q 37.55 Wed 17:00 Tent B

Characterization of second order noise processes in waveguide-based quantum frequency converters — •Ann-Kathrin Müller, Markus Struckmann, Florian Elsen, and Constantin Leon Häfner — Chair for Laser Technology, RWTH Aachen University

Quantum frequency converters (QFCs) are photonic interfaces that convert the photons emitted by qubits to the low-transmission-loss telecom bands for fiber-based quantum communication. They can be realized using difference-frequency-generation (DFG) with a strong laser field in periodically poled nonlinear materials, e.g. in a waveguide.

The aim is to maximize conversion efficiency whilst minimizing noise generation. Long-wavelength-pumped QFCs in which the strong light field is the lowest frequency component in the DFG process are theoretically considered quasi-noise-free.

However, during this work, noise characterization of a long-wavelength-pumped QFC from 856.7 nm to 1527.7 nm identified second harmonic generation (SHG) of the strong laser field with subsequent spontaneous parametric downconversion as a prominent noise source. Specifically, SHG-power in the milliwatt-regime was measured, showing the relevance of two-staged effects to noise in long-wavelength-pumped QFCs. This study advances the understanding of noise generation in QFCs, offering insights into the implications for QFC design and critical considerations for optimizing quantum networks.

Q 37.56 Wed 17:00 Tent B

Singular modes of light in dynamic random media — •David Bachmann[1], Mathieu Isoard[1,2], Giacomo Sorelli[1,3], Vyacheslav Shatokhin[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut der Albert-Ludwigs-Universität Freiburg — [2]Laboratoire Kastler Brossel, Paris, France — [3]Fraunhofer Institute for Optronics, Ettlingen, Germany

Wave propagation through random continuous media is an important fundamental problem with applications ranging from remote sensing to quantum communication. We refine the methods for accurate numerical simulation and table-top experiments of such media by introducing novel hybrid phase screens. Within this framework, we investigate the effects of disorder on structured light and show how instantaneous spatial singular modes of light offer improved high-fidelity signal transmission in dynamically evolving media compared to standard encoding bases. We show that power-law spectra such as the atmospheric Kolmogorov spectrum induce a subdiffusive algebraic decay of transmitted power as a function of time.

Q 37.57 Wed 17:00 Tent B

TOWARDS CONSUMER-LEVEL QUANTUM-SECURE CRYPTOGRAPHY ENTANGLEMENT-BASED SHORT-RANGE QUANTUM-KEY-DISTRIBUTION — •Luca Graf[1,2,3], Henning Mollenhauer[1,2,3], Till Appel[1,2,3], Daniel Tippel[1,2,3], Pius Gerisch[1,2,3], and Ralf Riedinger[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Deutschland

Over the last years various methods of quantum key distribution (QKD) have been developed. Long distance implementations remain challenging due to the exponential loss of photons in quantum channels. A possible solution is hybrid cryptography, with key distribution over short distance, followed by quantum-secure classical encryption over long distance. Short-range QKD allows for exchanging an information-theoretically secure root-of-trust that is stored on two end modules. This root-of-trust is employed to generate encryption keys through classical rekeying algorithm. In this approach it is possible to spatially separate the end modules and communicate over existing communication infrastructure since no quantum channel required after initialization. We present an experimental setup for short-range QKD with low-cost end modules that has the potential to be made compact enough to be implemented with semiconductor electronics.

Q 37.58 Wed 17:00 Tent B

Machine learning improved search for nitrogen-vacancy colour centres with long coherence times — •Ricky-Joe Plate, Jan Thieme, and Kilian Singer — Universität Kassel, Kassel, Germany

Nitrogen-vacancy colour centres are offering promising qubits for room temperature quantum information processing [1]. The quality of the qubits varies over a typical diamond sample and finding colour centres with long coherence times can be a time-consuming process in the lab. Here we present the architecture of a machine learning-based network [2] that allows for an automated search and characterization of optimal colour centres. An open-source implementation based on high-speed c++ code will be presented, that allows easy integration of custom improvements to the code base.

[1]: Maurer, P.C., Kucsko, G., Latta, C. (2012): Room-Temperature Quantum Bit Memory Exceeding One Second, in: Science Vol 336 Issue 6086, pp. 1283-1286, doi: 10.1126/science.1220513. [2]: Jiang, X., Hadid, A., Pang, Y., Granger, E. und Feng, X. (Hrsg.) (2019) Deep learning in object detection and recognition. Singapore: Springer.

Q 37.59 Wed 17:00 Tent B

A compact WGMR-based source optimized for coupling to an ion in a deep parabolic mirror — Sheng-Hsuan Huang[1,2], •Thomas Dirmeier[1,2], Martin Fischer[1,2], Markus Sondermann[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[2,1] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

As part of the BMBF QuNET initiative, it is planned to demonstrate the coupling of a mobile node containing a SPDC source to a stationary ion trap.

Cavity-assisted SPDC sources have been known to allow for the efficient coupling to atomic transitions. They often require additional spectral filtering cavities, thus leading to a higher experimental complexity. However, optical whispering gallery mode resonators (WGMR) have been proven to be compact, efficient and single mode sources of e.g. squeezed states or heralded single photons which can be coupled well to alkali metal vapours [1-3].

In our presentation, we discuss the concept and progress on the realization of a compact WGMR source that is specifically tailored to the $D_{3/2} \Leftrightarrow D[3/2]_{1/2}$ transition at 935 nm of $^{174}Yb^{+}$. We also highlight the challenges faced while developing a photon-ion-coupling experiment for a mobile platform, in this case an airplane.

[1]A.Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]G.Schunk, et.al., Journal of Modern Optics 63 (2016)
[3]M.Förtsch, et.al., Physical Review A 91(2) 023812 (2015)