BOOK OF ABSTRACTS

POSTER CONTRIBUTIONS

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1. CAUSAL PROCESS TOMOGRAPHY OF A FIBER-BASED QUANTUM SWITCH

MICHAEL ANTESBERGER

The field of indefinite causal order in quantum mechanics has seen more and more interest in the past years, both theoretically and experimentally. In such processes, different parties act in a superposition of different orders. Since the first experimental realization of a process with an indefinite causal order, the quantum SWITCH, several protocols taking advantage of this new resource have emerged. In previous experiments, the causal non-separability of two parties has been verified by measuring a so-called 'causal witness'. Nevertheless, the corresponding process matrix has only been evaluated theoretically. Here, we experimentally reconstruct the process matrix of a new passively-stable fiber-based architecture for the quantum SWITCH based on time-bin encoded qubits, which can readily be scaled to more parties. We perform a full characterization of this new type of quantum SWITCH by implementing causal process tomography for the first time. We then compare the tomography results to those obtained by directly measuring several different causal witnesses. Finally, we present the first measurement of the fidelity of our experimental quantum SWITCH to the ideal quantum SWITCH.

2. RELATIVISTIC QUANTUM REFERENCE FRAMES

LUCA APADULA

The framework of Quantum Reference Frames (QRFs) is based on the assumption that quantum states are carriers of viable frame of reference. As a matter fact, they are used as a programming resource for a reference frame transformation, that corresponds to a specific symmetry group. In this work we conceive a QRF as a system undergoing relativistic dynamics. First, we give the definition of quantum spacetime state, resembling the special-relativistic symmetry between time and space coordinates and also allowing to extend the state localisation to an arbitrary spacetime volume. Subsequently, we recover a possible definition of Lorentz transformation between relativistic quantum reference frames (RQRFs), resulting in a notion of Lorentz covariance for RQRFs. The result is a wider phenomenology that cannot be recover within the usual Lorentz group, e.g. superposition of simultaneity surfaces, of special-relativistic time dilations and length contractions. This scenario opens up the possibility to give a quantum formulation of the spacial-relativistic notion of event, as a quantum understanding of Minkowskian spacetime geometry.

3. LARGE FLUX-MEDIATED COUPLING IN HYBRID ELECTROMECHANICAL SYSTEM WITH A TRANSMON QUBIT

TANMOY BERA

Control over the quantum states of a massive oscillator is important for several technological applications and to test the fundamental limits of quantum mechanics. Addition of an internal degree of freedom to the oscillator could be a valuable resource for such control. Recently, hybrid electromechanical systems using superconducting qubits, based on electric-charge mediated coupling, have been quite successful. Here, we show a hybrid device, consisting of a superconducting transmon qubit and a mechanical resonator coupled using the magnetic-flux. The coupling stems from the quantum-interference of the superconducting phase across the tunnel junctions. We demonstrate a vacuum electromechanical coupling rate up to 4 kHz by making the transmon qubit resonant with the readout cavity. Consequently, thermal-motion of the mechanical resonator is detected by driving the hybridized-mode with mean-occupancy well below one photon. By tuning qubit away from the cavity, electromechanical coupling can be enhanced to 40 kHz. In this limit, a small coherent drive on the mechanical resonator results in the splitting of qubit spectrum, and we observe interference signature arising from the Landau-Zener-Stückelberg effect. With improvements in qubit coherence, this system offers a platform to realize rich interactionss and could potentially provide full control over the motional states.

4. JOINT MEASURABILITY IN NON-EQUILIBRIUM QUANTUM THERMODYNAMICS

KONSTANTIN BEYER

The two-point measurement (TPM) scheme is one of the standard approaches to define work in non-equilibirum quantum thermodynamics. The energy of a closed system is measured projectively at the beginning and at the end of the protocol. The work for a single run is then given by the energy difference. The measurement statistics for an initial Gibbs state fulfills the Jarzynski equality and allows us to determine the free energy difference. On the other hand, for initial states with coherences the projective TPM does not yield the correct average work because the first measurement is inherently disturbing. It is well known that a projective TPM scheme cannot be replaced by a single work measurement that reproduces both the TPM statistics for diagonal input states and the correct average work for arbitrary states. However, projective measurements are an idealization. Therefore, we extend the scenario to less disturbing unsharp energy measurements and show that the no-go theorem does not apply if the (unsharp) energies at the beginning and at the end of the protocol can be measured jointly for any intermediate unitary evolution. In such a case the average work and the free energy difference can be determined with the same measurement setup.

5. DISSIPATIVE PHASE TRANSITION IN OPTOMECHANICAL SYSTEMS

FATEMEH BIBAK

In this work, we studied dissipative phase transitions (DPT) in the optomechanical systems. We applied the stability analysis at a well-defined thermodynamic limit to arrive at the corresponding phase diagram which exhibits two types of instability lines: soft and hard mode instabilities—directly related to DPTs. The optomechanical phase diagram exhibits rich structure composed of first and second-order DPT (with and without symmetry breaking). The analysis is supplemented with the computation of critical exponents and corresponding universality class. Finally, we studied quantum properties of the steady-state quantified via squeezing and entanglement. We demonstrate that one can boost these quantities by applying auxiliary passive linear optic operations to the steady-state.

6. MULTIPLE PROJECTION TOMOGRAPHY TOWARDS MINIMUM-ERROR QUANTUM MEASUREMENT

MARTIN BIELAK

Accurate characterization of quantum states plays a fundamental role in quantum science. The full characterization of a quantum state requires a tomographic procedure consisting of various measurements performed on a limited number of copies of the state. The choice of the individual measurements, often local and projective, fundamentally affects the performance of the tomographic scheme. It turns out that despite the increased noise due to the decreasing photon flux per projection, overcomplete multi-projector tomography yields a significant reduction in the resulting measurement error. We present detailed numerical simulations and the first experimental demonstration of one- and two-qubit overcomplete tomographic measurements that outperform state-of-the-art approaches. We also experimentally demonstrate tomographic schemes with a high number of random projective measurements of up to 120 projections per qubit. The reported informationally overcomplete measurements represent a remarkable strategy for the complete local characterization of entangled quantum states and quantum devices, leading to the efficient use of available resources. Despite the challenging experimental implementation and seemingly higher sampling noise, this strategy significantly outperforms conventional measurement methods.

7. TRANSCENDENTAL PROPERTIES OF ENTROPY-CONSTRAINED SETS

VJOSA BLAKAJ

For information-theoretic quantities with an asymptotic operational characterization, the question arises whether an alternative single-shot characterization exists, possibly including an optimization over an ancilla system. If the expressions are algebraic and the ancilla is finite, this leads to semialgebraic level sets. In this work, we provide a criterion for disproving that a set is semialgebraic based on an analytic continuation of the Gauss map. Applied to the von Neumann entropy, this shows that its level sets are nowhere semialgebraic in dimension $d > 2$, ruling out algebraic single-shot characterizations with finite ancilla (e.g., via catalytic transformations). We show similar results for related quantities, including the relative entropy, and discuss under which conditions entropy values are transcendental, algebraic, or rational.

8. CORRELATION SPECTROSCOPY WITH MULTI-QUBIT-ENHANCED PHASE ESTIMATION IN A PLANAR 91-ION CRYSTAL

MATTHIAS BOCK

Trapped ions are a well-established platform for quantum simulations of quantum magnetism. Up to now, ions in linear Paul traps allow for simulations of the 1D Ising model with up to 50 spins. We aim for extending this approach to the second dimension to enable quantum simulations with larger particle numbers (> 50) as well as studies of 2D spin physics. Here we present a new ion trap apparatus which is currently capable of trapping stable 2D crystals with up to 100 Ca-ions. Its centerpiece is a monolithic micro-fabricated linear Paul trap, enabling us to create the required anisotropic trapping potentials. As a first application, we perform correlation spectroscopy in a 91-ion planar crystal. Correlation spectroscopy is a technique to probe phase differences between qubits in the presence of correlated phase noise even if the probe times are much longer than the coherence time of the qubits. We utilize this technique to sense a magnetic field gradient, which gives rise to transition frequency differences across the ion crystal. Furthermore, we demonstrate that the information contained in the 91-particle correlations enhances the phase estimation by reducing its measurement uncertainty as compared to the case where only two-particle correlations are analyzed, and that the advantage of using entangled states for this specific purpose becomes negligible for an infinite number of qubits.

9. ROBUST NEAR-UNITY CAVITY-TO-FIBER COUPLING OF LIGHT EMITTED BY DIAMOND COLOR CENTERS EMBEDDED IN 'SAWFISH' PHOTONIC CRYSTAL CAVITIES

JULIAN BOPP

Color centers in diamond are promising candidates to be used as quantum memories and quantum emitters [1]. Nowadays, it remains challenging to couple light emitted from a single color center located in a diamond cavity efficiently to a traveling light mode of a connected waveguide [2]. Low coupling efficiencies hamper utilizing color centers as single-photon sources in photonic integrated circuits (PICs) to realize quantum repeaters for a secure and large-scale quantum internet [3]. Here, we present finite element simulations of the 'Sawfish' cavity, a novel waveguide-integrated photonic crystal cavity designed to transfer the zero phonon line emission of diamond color centers with near-unity efficiency into a single-mode fiber. Consisting of relatively large features, the investigated cavity mitigates fabrication challenges and reveals robustness under realistic conditions while maintaining high quality factors and small mode volumes in simulations.

[1] S. Mouradian et al., Phys. Rev. X 5, 031009 (2015) [2] S. Mouradian et al., Appl. Phys. Lett. 111, 021103 (2017) [3] J. Borregaard et al., Phys. Rev. X 10, 021071 (2020)

10. SUPERRADIANT LASING IN INHOMOGENEOUSLY BROADENED ENSEMBLES

ANNA BYCHEK

Theoretical studies of superradiant lasing on optical clock transitions predict a superb frequency accuracy and precision closely tied to the bare atomic linewidth [1]. Such a superradiant laser is also robust against cavity fluctuations when operated in a bad-cavity regime. Recent predictions suggest that this unique feature persists even for a hot and thus strongly broadened ensemble, provided the effective atom number is large enough. Here we use a second-order cumulant expansion approach to study the power, linewidth and lineshifts of such a superradiant laser as a function of the inhomogeneous width of the ensemble. We show how sufficiently large numbers of atoms subject to strong optical pumping can induce synchronization of the atomic dipoles over a large bandwidth. This generates collective stimulated emission of light into the cavity mode leading to narrow-band laser emission at the average of the atomic frequency distribution. The linewidth is orders of magnitudes smaller than that of the cavity as well as the inhomogeneous gain broadening and exhibits reduced sensitivity to cavity frequency noise [2].

[1] D. Meiser, J. Ye, D. R. Carlson, M. J. Holland, Phys. Rev. Let. 102(16) 163601 (2009). [2] A. Bychek, C. Hotter, D. Plankensteiner, H. Ritsch, Open Research Europe 1:73 (2021)

11. ENGINEERING ENTANGLED PHOTONS FOR TRANSMISSION IN RING-CORE OPTICAL FIBERS

GUSTAVO CAÑAS

The capacity of optical communication channels can be increased by space division multiplexing in structured optical fibers. Radial core optical fibers allows for the propagation of twisted light−eigenmodes of orbital angular momentum, which have attracted considerable attention for high-dimensional quantum information. Here we study the generation of entangled photons that are tailor-made for coupling into ring core optical fibers. We show that the coupling of photon pairs produced by parametric downconversion can be increased by close to a factor of three by pumping the non-linear crystal with a perfect vortex mode with orbital angular momentum ℓ, rather than a gaussian mode. Moreover, the two-photon orbital angular momentum spectrum has a nearly constant shape. This provides an interesting scenario for quantum state engineering, as pumping the crystal with a superposition of perfect vortex modes can be used in conjunction with the mode filtering properties of the ring core fiber to produce simple and interesting quantum states.

12. SYMMETRY-RESOLVED ENTANGLEMENT DETECTION USING PARTIAL TRANSPOSE MOMENTS

JOSE CARRASCO

We propose an ordered set of experimentally accessible conditions for detecting entanglement in mixed states. The k-th condition involves comparing moments of the partially transposed density operator up to order k. Remarkably, the union of all moment inequalities reproduces the Peres-Horodecki criterion for detecting entanglement. Our empirical studies highlight that the first four conditions already detect mixed state entanglement reliably in a variety of quantum architectures. Exploiting symmetries can help to further improve their detection capabilities. We also show how to estimate moment inequalities based on local random measurements of single state copies (classical shadows) and derive statistically sound confidence intervals as a function of the number of performed measurements. Our analysis includes the experimentally relevant situation of drifting sources, i.e. non-identical, but independent, state copies

13. QUANTUM GENERALISATION OF EINSTEIN'S EQUIVALENCE PRINCIPLE CAN BE VERIFIED WITH ENTANGLED CLOCKS AS QUANTUM REFERENCE FRAMES

CARLO CEPOLLARO

The Einstein Equivalence Principle (EEP) is of crucial importance to test the foundations of general relativity. When the particles involved in the test exhibit quantum properties, it is unknown whether this principle still holds. A possibility introduced in arXiv:2012.13754 is that the EEP holds in a generalised form for particles having an arbitrary quantum state. The core of this proposal is the ability to transform to a Quantum Reference Frame (QRF) associated to an arbitrary quantum state of a physical system, in which the metric is locally inertial. Here, we show that this extended EEP, initially formulated in terms of the local expression of the metric field in a QRF, can be verified in an interferometric setup via tests on the proper time of entangled clocks. We find that the violation of the generalised EEP corresponds to the impossibility of defining dynamical evolution in the frame of each clock. The violation results in a modification to the probabilities of measurements calculated in the laboratory frame, and hence can be verified in an interferometric setting.

14. STATISTICAL TIME-DOMAIN CHARACTERIZATION OF NON-PERIODIC OPTICAL CLOCKS

DARIO CILLUFFO

Measuring time means counting the occurrence of periodic phenomena. Over the past centuries a major effort was put to make stable and precise oscillators to be used as clock regulators. Here we consider a different class of clocks based on stochastic clicking processes. We provide a rigorous statistical framework to study the performances of such devices and apply our results to a single coherently driven two-level atom under photodetection as an extreme example of non-periodic clock. Quantum Jump MonteCarlo simulations and photon counting waiting time distribution will provide independent checks on the main results.

- D. Cilluffo, Quantum 6, 764 (2022) - G. J. Milburn, Contemporary Physics 61, 69–95 (2020) - H. Touchette, Physics Reports 478, 1–69 (2009). - J. P. Garrahan, I. Lesanovsky, Phys. Rev. Lett. 104, 160601 (2010).

15. TOWARDS CAVITY-ENHANCED PHOTON EMISSION FROM LOW-NOISE NITROGEN-VACANCY CENTERS IN DIAMOND

ANDREA CORAZZA

A spin-photon interface is a key building block in a quantum network as it establishes remote spin-spin entanglement among the nodes. A promising spin-photon interface is the Nitrogen-Vacancy (NV) center in diamond, a highly coherent and optically addressable electron spin, coupled to an open Fabry-Perot microcavity. The cavity acts both on the NVs long radiative lifetime via the Purcell effect and on the NVs low branching ratio via the cavity coupling, enhancing the coherent photon flux. To incorporate NV centers into a microcavity, the host material needs to be thinned down to a micrometric scale while maintaining the NVs optical coherence, a well-known challenge in the field. We present an improved NV creation protocol in which we implant carbon ions, instead of nitrogen ions, once all the diamond fabrication has been completed. We show excellent NV optical coherence (over 50% of the NVs optical linewidths < 150MHz) even in membranes thinner than 2 μm. The characterization of the cavity at cryogenic temperatures shows Q-factors up to 127000, corresponding to a finesse of 7900. The coupling of a single NV center to a cavity mode then results in a Purcell enhancement of the radiative decay rate by a factor of 30. If the photon detection efficiency can be increased, we argue that the success probability of remote spin-spin entanglement would be enhanced by more than two orders of magnitude.

16. PREPARATION AND VERIFICATION OF TENSOR NETWORK STATES

ESTHER CRUZ RICO

We consider a family of tensor network states defined on regular lattices that come with a natural definition of an adiabatic path to prepare them. This family comprises relevant classes of states, such as injective Matrix Product and Projected Entangled-Pair States, and some corresponding to classical spin models. We show how uniform lower bounds to the gap of the parent Hamiltonian along the adiabatic trajectory can be efficiently computed using semi-definite programming. This allows one to check whether the adiabatic preparation can be performed efficiently with a scalable effort. We also derive a set of observables whose expectation values can be easily determined and that form a complete set, in the sense that they uniquely characterize the state. We identify a subset of those observables which can be efficiently computed if one has access to the quantum state and local measurements, and analyze how they can be used in verification procedures

17. SPACETIMES IN SUPERPOSITION: EXTENDED SYMMETRIES OF THE KLEIN-GORDON FIELD

ANNE-CATHERINE DE LA HAMETTE

Given the broadly accepted theories of quantum mechanics and general relativity, there is no clear answer to the question of how fields and particles behave on a quantum superposition of spacetimes. In the present work, we consider superpositions of conformally equivalent metrics inhabited by a massive quantized Klein-Gordon (KG) field. By requiring invariance of the KG equation under quantum conformal transformations, we find that the superposition is transferred to an effective, spacetime dependent mass term. Based on the group structure of this transformation, we are able to construct an explicit quantum operator, in the spirit of the quantum reference frame formalism, that can map states describing a quantum field on a superposition of spacetimes to states representing a superposition of quantum fields with modified mass on a Minkowski background. This constitutes an extended symmetry principle, namely invariance under quantum conformal transformations. The latter allows to build intuition for superpositions of spacetimes by relating it to situations that are more easily cast in the language of QFTCS. Furthermore, it can be used to import the phenomenon of particle production in curved spacetime to its conformally equivalent counterpart, thus revealing new features in modified Minkowski spacetime.

18. DIGITAL SIMULATION OF A SPIN-1 CHAIN

CLAIRE EDMUNDS

Understanding the quantum properties that describe topological matter has the potential to stimulate novel materials development and enable robust quantum information manipulation. The complexity of such materials exceeds classical capabilities but is well-suited for study by digital quantum simulation, which replicates the energy dynamics in a controlled, gate-based manner. I will demonstrate the quantum simulation of a topological spin chain on a trapped-ion quantum processor. Combining higher-dimensional “qudit” trapped-ion systems [1] with digital quantum simulation [2] enables us to study not only condensed matter properties, but also quantum information properties of the system. In particular, we study correlation and entanglement, as well as error-robust edge modes that arise due to topological symmetry in our material. In addition, I will discuss the integration of quantum control techniques to mitigate gate errors during quantum simulation [3, 4].

[1] M. Ringbauer et al., arxiv:2109.06903 (2021) [2] B. Lanyon et al., Science 334, 57 (2011) [3] Edmunds, C. L. et al., Phys. Rev. Research 2, 013156 (2020) [4] Milne, A. R. et al., Phys. Rev. Applied 13, 024022 (2020)

19. TITLE TBT

SAMUEL ELMAN

We present a simple criterion to determine whether the model admits an exact description by effective noninteracting fermions, yielding an exact solution. Our criterion is given in terms of the model's frustration graph, the network of pairwise anticommutation relations between Pauli terms of the Hamiltonian written in a given basis. When this graph is claw-free, and contains a simplicial clique as an induced subgraph, then an exact solution exists. This unifies characterizations given in previous work, where it was shown that a free-fermion mapping exists when this graph is either a line graph, or (even-hole, claw)-free. The former case captures injective mappings from Hamiltonian terms to free-fermion terms, including the Jordan-Wigner transformation and the exact solution to the Kitaev honeycomb model. The latter case generalizes a recent, nonlocal solution to the four-fermion model given by Fendley. Our characterization unifies these two approaches, extending the generalized Jordan-Wigner solutions to the nonlocal case and extending the generalized four-fermion solution to arbitrary spatial dimension. Our key technical insight is the identification of a class of cycle symmetries for all models with a claw-free frustration graph.

20. PARTY-LOCAL CLIFFORD TRANSFORMATIONS OF STABILIZER STATES

MATTHIAS ENGLBRECHT

Stabilizer states and graph states find application in quantum error correction, measurement-based quantum computation and various other concepts in quantum information theory. In this work, we study party-local Clifford (PLC) transformations among stabilizer states. These transformations arise as a physically motivated extension of local operations in quantum networks with access to bipartite entanglement between some of the nodes of the network. First, we show that PLC transformations among graph states are equivalent to a generalization of the well-known local complementation, which describes local Clifford transformations among graph states. Then, we introduce a new mathematical framework to study PLC equivalence of stabilizer states. This framework allows us to study decompositions of stabilizer states into tensor products of indecomposable ones, that is, decompositions into states from the entanglement generating set (EGS). While the EGS is finite up to 3 parties [1], we show that for 4 and more parties it is an infinite set. Finally, we generalize the framework to qudit stabilizer states in prime dimensions not equal to 2, which allows us to show that qudit stabilizer states decompose uniquely into states from the EGS.

[1] Bravyi, Sergey, David Fattal, Daniel Gottesman, Journal of Mathematical Physics 47.6 (2006): 062106.

21. NONDESTRUCTIVE DETECTION OF PHOTONIC QUBITS

PAU FARRERA

Qubits encoded in single photons are very useful to distribute quantum information over remote locations, but at the same time are also very fragile objects. The loss of photonic qubits (through absorption, diffraction or scattering) is actually the main limitation in the maximum reachable quantum communication distance. In this context, the nondestructive detection of photonic qubits is a great scientific challenge that can help tracking the qubit transmission and mitigate the loss problem. We recently implemented such a detector [1] with a single atom coupled to two crossed fiber-based optical resonators, one for qubit-insensitive atom–photon coupling and the other for atomic-state detection. We achieve a nondestructive detection efficiency of 79 ± 3 % conditioned on the survival of the photonic qubit, a photon survival probability of 31 ± 1 %, and we preserve the qubit information with a fidelity of 96.2 ± 0.3 %. To illustrate the potential of our detector we show that it can provide an advantage for long-distance entanglement and quantum-state distribution, resource optimization via qubit amplification, and detection-loophole-free Bell tests.

[1] D. Niemietz et al., Nature 591, 570–574 (2021)

22. PROGRESS TOWARDS QUANTUM TELEPORTATION IN AN ATOM-OPTOMECHANICAL SYSTEM

SERGEY FEDOROV & PEYMAN MALEKZADEH

Quantum mechanics dictates irreducible limits of noise for certain measurements. Developing the theory of these limits and experimentally validating them provides insights in fundamental physics and offers better measurement schemes that are less susceptible to quantum noise. Continuous quantum measurements in a hybrid system consisting of a mechanical oscillator, whose position modulates the phase of a light field, and a collective atomic spin probed via Faraday rotation of the same light field have been experimentally demonstrated. They were applied to force metrology and entanglement generation between the atomic ensemble and the mechanical oscillator. Building on those works, we aim to teleport a quantum state from one system to another, thus realizing state transfer between two macroscopic systems of different physical natures. Towards this goal, we report advances in developing a quantum interface between an ensemble of spins in a room temperature gas cell and a membrane-in-the-middle optomechanical cavity.

23. UNIVERSAL PARITY QUANTUM COMPUTING

MICHAEL FELLNER

We propose a universal gate set for quantum computing with all-to-all connectivity and intrinsic robustness to bit-flip errors based on the parity encoding. We show that logical CPhase gates and Rz rotations can be implemented in the parity encoding with single-qubit operations. Together with logical Rx rotations, implemented via nearest-neighbor CNOT gates and an Rx rotation, these form a universal gate set. As the CPhase gate requires only single qubit rotations, the proposed scheme has advantages for several cornerstone quantum algorithms, e.g., the Quantum Fourier Transform. We present a method to switch between different encoding variants via partial on-the-fly encoding and decoding.

24. THERMODYNAMIC COST-BENEFIT TRADE-OFFS OF LEARNING AGENTS

LUKAS FIDERER

Paradigmatic thermodynamic examples such as Maxwell's demon or Szilárd's engine only consider the thermodynamic cost of executing an optimal policy while the cost of learning this policy is ignored. However, in many practical situations the cost of learning is of crucial importance. In this work, we show what is the minimal thermodynamic cost an agent must pay to learn. To this end, we formalize reinforcement learning within a physically motivated memory-based agent-environment model. Based on this model, we consider random search and reinforcement learning strategies of an agent and show when a fundamental lower bound on the thermodynamic cost of learning a policy can be saturated. A particularly interesting problem arises when the agent must learn how to extract work. We characterize the trade-off between the thermodynamic cost of learning and the benefits of work extraction and consider a partially observable Szilárd engine as an example. Our work promises to be helpful in devising new resource-efficient learning algorithms, represents a step towards a more physical model of agency, and may contribute to a better understanding of the emergence of intelligent behavior in varying environments.

25. QUANTUM NON-GAUSSIAN HIERARCHY FOR PHOTONS AND PHONONS

RADIM FILIP

The poster will report recent theoretical and experimental achievements opening the door to highly non-Gaussian quantum physics with light and mechanical oscillators. This territory is challenging for investigation, both theoretically and experimentally. After briefly introducing the quantum non-Gaussian effects for light (Phys. Rev. Lett. 123, 043601 (2019), Phys. Rev. Lett. 126, 213604 (2021)), we will present recent theoretical and experimental activities, including the faithful hierarchy of quantum non-Gaussianity for multiphonon generation, its unpublished experimental verification and sensing capabilities (arXiv:2111.10129; accepted to PRL). Further, we will continue recent experimental results on generating quantum non-Gaussianity of light from hot atomic ensembles (arXiv:2201.05366) and proposal for highly quantum non-Gaussian states of optomechanical systems and superconducting circuits (npj Quantum Information 7, 120 (2021)). The poster will conclude with other related results and the following challenges in theory and experiments with light, mechanical oscillators and superconducting circuits to stimulate discussion and further development of this field.

26. A STABLE OPEN-ACCESS OPTICAL MICROCAVITY AS A PLATFORM FOR QUANTUM ACOUSTICS

MATTEO FISICARO

Open access optical microcavities are a promising alternative to monolithic cavities due to their versatility and spatial and frequency tunability. Because of their mechanical complexity they often are sensitive to vibrations and require liquid-Helium cryostats. Here we show an open cavity device that is suited for operation in a closed-cycle cryostat without compromising tunability. The device shows a rms cavity length stability of 18 pm at 4K in a commercial closed-cycle cryostat, allowing operation of cavities with finesse of few thousands. We will show first steps towards using our device for quantum dot cavity-QED; in particular, we aim to use the device as a platform for quantum acoustics experiments. On the flat mirror we fabricate an interdigital transducer (IDT) capable of exciting GHz surface acoustic waves (SAW). The detection of these mechanical waves can be carried out interferometrically or by detecting the quantum-confined Stark shift of a single quantum dot embedded in the mirror, allowing in principle the detection of single phonons.

27. PROJECTIVE SIMULATION BASED ON SINGLE-PHOTON QUANTUM WALKS IN LINEAR OPTICAL INTERFEROMETERS

FULVIO FLAMINI

Variational circuits are gaining large momentum for the implementation of near-term quantum machine learning, mostly thanks to their intuitive description and resilience to noise. In this context, we present a variational approach to quantum machine learning, and specifically to reinforcement learning, based on single-photon quantum walks in linear optical interferometers. This can be seen as a quantum analogue of a classical reinforcement learning method called projective simulation. The proposed architecture consists of a regular mesh of tunable Mach-Zehnder interferometers, which are individually addressed to perform learning strategies tailored to this approach. Preliminary numerical results show its potential for the integration of learning algorithms in quantum optical applications.

28. MACROSCOPICALLY NONLOCAL QUANTUM CORRELATIONS

MIGUEL GALLEGO

It is usually believed that coarse-graining of quantum correlations leads to classical correlations in the macroscopic limit. Such a principle, known as macroscopic locality, has been proved for correlations arising from independent and identically distributed (IID) entangled pairs. In this letter we consider the generic (non-IID) scenario. We find that the Hilbert space structure of quantum theory can be preserved in the macroscopic limit. This leads directly to a Bell violation for coarse-grained collective measurements, thus breaking the principle of macroscopic locality.

29. ENTANGLEMENT BETWEEN REMOTE IONS INTERFACED WITH CAVITIES

MARIA GALLI

In a quantum network, entanglement between matter-based qubits located in remote nodes is a fundamental resource for different applications, including distributed quantum computing and quantum repeaters. In recent years, research groups working on different platforms have demonstrated entanglement over distances up to 33 km. However, entanglement between two ions has never been achieved for distances longer than few meters. If this capability were in place, quantum network protocols such as teleportation could be performed with systems based on trapped ions, which – thanks to their characteristics, such as efficient interfacing with telecom-wavelength photons and long coherence times – are promising candidates for quantum network applications. One can generate entanglement between distant ions by creating an ion-photon entangled pair at each of two network nodes, steering the photons to opposite input ports of a beamsplitter, and detecting them at the beamsplitter outputs. Specific photon detection patterns herald the generation of an ion-ion entangled state. Here, we present entanglement between two cavity-coupled remote ions linked via an optical-fiber channel 500 m long. The achieved fidelity with respect to a maximally entangled state is more than 6 standard deviations above the classical limit.

30. IMPROVING QUANTUM STATE DETECTION WITH ADAPTIVE SEQUENTIAL OBSERVATIONS

SHAWN GELLER

For many quantum systems intended for information processing, one detects the logical state of a qubit by integrating a continuously observed quantity over time. For example, ion and atom qubits are typically measured by driving a cycling transition and counting the number of photons observed from the resulting fluorescence. Instead of recording only the total observed count in a fixed time interval, one can observe the photon arrival times and get a state detection advantage by using the temporal structure in a model such as a Hidden Markov Model. We study what further advantage may be achieved by applying pulses to adaptively transform the state during the observation. We give a three-state example where adaptively chosen transformations yield a clear advantage, and we compare performances on an ion example, where we see improvements in some regimes.

31. EXPLOITING SPIN-ORBIT COUPLED INTERACTING QUANTUM GASES TO OVERCOME THE HEISENBERG LIMIT

KAROL GIETKA

In quantum metrology, one typically creates correlations among atoms or photons to enhance measurement precision. Here, we show how one can use other excitations to perform quantum-enhanced measurements on the example of center-of-mass excitations of a spin-orbit coupled Bose-Einstein condensate and a Coulomb crystal. We also present a method to simulate a homodyne detection of center-of-mass excitations in these systems, which is required for optimal estimation. Subsequently, we consider a spin-orbit coupled Fermi gas and show how this system can be used to overcome the Heisenberg scaling of the sensitivity when estimating an unknown parameter.

32. ERROR PROPAGATION IN NISQ DEVICES FOR SOLVING CLASSICAL OPTIMIZATION PROBLEMS

GUILLERMO GONZALEZ GARCIA

We propose a random circuit model to analyze the impact of noise on the performance of variational quantum circuits for classical optimization problems. Our model accounts for the propagation of arbitrary single qubit errors through the circuit. We find that even with a small noise rate, the quality of the obtained classical optima is low on average. As a consequence, a single-qubit error rate of the order of 1/(nD) is needed for the possibility of a quantum advantage, where n is the number of qubits and D is the circuit depth. We estimate that this translates to an error rate lower than 10^-6 using QAOA for classical optimization problems with 2D circuits.

33. COUPLING ERBIUM DOPANTS TO NANOPHOTONIC SILICON STRUCTURES

ANDREAS GRITSCH

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence [1] with coherent optical transitions at telecommunication wavelength [2]. Among potential host crystals for erbium, silicon stands out because of its compatibility with CMOS technology which allows scalable fabrication of nanophotonic devices. In contrast to observations of our previous studies [3], we have recently shown that erbium ions implanted into silicon nanostructures are located on a few well-defined lattice sites with narrow inhomogeneous (~0.5 GHz) and homogeneous (<0.02 MHz) linewidths [4]. To harness our novel material platform for quantum networks, we proceed towards the control of individual erbium dopants. As the long lifetime of the optically excited state, around 0.25 ms, would limit the achievable rates, we designed and fabricated photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to resolve and control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing over large distances.

[1] M. Rancic, et.al. Nat. Physics, 14, 50-54 (2018) [2] B. Merkel, et.al., Phys. Rev. X 10, 041025 (2020). [3] L. Weiss, et.al. Optica, 8, 40-41 (2021) [4] A. Gritsch, et.al. arXiv.2108.05120

34. ENTANGLEMENT AND QUANTUM INFORMATION

DAVID KENWOTHY GUNN

Studying transformations via Local Operations assisted by Classical Communication (LOCC) between pure states has led to considerable insight into entanglement. However, in any physical setting, one never works exactly with pure states but instead with some nearby (potentially mixed) states. As a result, in this work, we investigate approximate LOCC transformations. For such transformations, we show it is sufficient to consider pure initial states, as well as LOCC protocols with a finite number of rounds. We also demonstrate the difference between bipartite and multipartite approximate LOCC and investigate the extent to which approximate LOCC allows for new transformations.

35. STRAIN-CONTROLLED QUANTUM DOT FINE STRUCTURE FOR ENTANGLED PHOTON GENERATION AT 1550 NM

SAMUEL GYGER

Semiconductor quantum dots, a type of solid-state emitters, are a promising technology platform for generating single and entangled photons. The biexciton-exciton cascade allows for very low multi-photon emission and the generation of highly entangled single photon pairs. To achieve emission at 1550 nm, InAs quantum dots can be grown on a metamorphic buffer layer. The exciton level is degenerate in the ideal case, but local anisotropy in the quantum dots causes fine structure splitting (FSS), which reduces the usefulness of the photons. Using a micromachined piezoelectric actuator that allows for strain control in three directions separated by 60°, we demonstrate vanishing FSS of the quantum dot. When implementing quantum protocols, this reduces the need for high time resolution and synchronization.We can then investigate the entangled photons generated by the same quantum dot at various FSS values thanks to the tunability over a range of 11 µeV. The results were published in Lettner et al. Nano Lett.2021, 21, 24, 10501–10506.

36. COOPERATIVE SUBWAVELENGTH MOLECULAR QUANTUM EMITTER ARRAYS

RAPHAEL HOLZINGER

Dipole-coupled subwavelength quantum emitter arrays respond cooperatively to external light fields as they may host collective delocalized excitations (a form of excitons) with super- or subradiant character. Deeply subwavelength separations typically occur in molecular ensembles, where in addition to photon-electron interactions, electron-vibron couplings and vibrational relaxation processes play an important role. While vibrations are typically considered detrimental to coherent dynamics, we show that molecular dimers or rings can be operated as platforms for the preparation of long-lived dark superposition states aided by vibrational relaxation.

37. ACCESSING INACCESSIBLE INFORMATION VIA QUANTUM INDISTINGUISHABILITY

SEBASTIAN HORVAT

Suppose that Alice stumbles upon a box containing some confidential information and wishes to read out the latter. The problem is that the box is practically unbreakable and the information is so encoded as not to leave any physical trace in the environment, thereby leaving Alice with apparently no means of gathering the information. While the information is per assumption inaccessible classically, we show that it can be read out almost perfectly within quantum mechanics. Interestingly, the task can be accomplished only if Alice employs additional boxes, which need to be identical to the initial one in the quantum-mechanical sense. After formalizing the task we show how its solution relies on an interplay between entanglement and quantum indistinguishability. We also discuss the broader merit of our findings, thereby pointing out their relevance for quantum information processing.

38. A COMPLETE POVM DESCRIPTION OF MULTI-CHANNEL QUANTUM ELECTRO-OPTIC SAMPLING WITH MONOCHROMATIC FIELD MODES

EMANUEL HUBENSCHMID

We propose a multi-channel version of quantum electro-optic sampling involving monochromatic field modes. It allows for multiple measurements of arbitrary X and Y field-quadrature combinations for a single quantum-state copy, while independently tuning the interaction strengths at each channel. In contrast to standard electro-optic sampling, the sampled mid-infrared (MIR) mode undergoes a nonlinear interaction with multiple near-infrared (NIR) pump beams. We present a complete positive operator-valued measure (POVM) description for quantum states in the MIR mode. The probability distribution of the electro-optic signal outcomes is shown to be related to a phase-space quasi-probability distribution of the indirectly measured MIR state, with the (extended) annihilation-creation operator ordering depending solely on the parameters characterizing the nonlinear interaction. Furthermore, we show that the quasi-probability distributions for the sampled and post-measurement states are related to each other through a renormalization and a change in the operator ordering. This result is then used to demonstrate that two consecutive measurements of both X and Y quadratures can outperform eight-port homodyne detection.

39. DYNAMICS OF ENTROPY PRODUCTION RATE AND QUANTUM CORRELATIONS IN TWO COUPLED BOSONIC MODES INTERACTING WITH A THERMAL RESERVOIR

AURELIAN ISAR

The Markovian time evolution of the entropy production rate is studied as a measure of irreversibility generated in a bipartite quantum system consisting of two coupled bosonic modes immersed in a common thermal environment. The dynamics of the system is described in the framework of the formalism of the theory of open quantum systems based on completely positive quantum dynamical semigroups, for initial two-mode squeezed thermal states, squeezed vacuum states, thermal states and coherent states. We show that the rate of the entropy production of the initial state and nonequilibrium stationary state, and the time evolution of the rate of entropy production, strongly depend on the parameters of the initial Gaussian state, frequencies of modes, parameters characterising the thermal environment, and the strength of coupling between the two modes. We also provide a comparison of the behaviour of entropy production rate and the quantum correlations present in the considered system (Rényi-2 mutual information, Rényi-2 quantum discord and entanglement) [1].

[1] Tatiana Mihaescu, Aurelian Isar, Entropy, 24, 696 (2022)

40. PHOTON PAIR GENERATION IN ULTRA-THIN FILMS WITHOUT PHASE-MATCHING

PHILIPP JENKE

In sufficiently thin nonlinear materials, the phase-matching condition of processes like parametric down-conversion or four-wave mixing relaxes. We characterize the resulting broadband biphoton states by stimulated emission tomography, and present progress towards photon pair generation in ultra-thin films. Our optical nonlinear film (much thinner than the pump wavelength) imposes energy conservation as the only requirement in the nonlinear interaction, resulting in strong two-photon energy correlations. Additionally, the absence of phase-matching means that the photon pairs are highly entangled in frequency and separable in all other degrees of freedom. Using stimulated emission tomography we characterize the joint spectral intensity of the generated biphoton state. We keep the pump wavelength constant and stimulate the FWM process with different wavelengths. The measured spectral width of the state extends over tens of THz. To conclude, broadband stimulated emission tomography measurements on ultra-thin films have been successfully demonstrated, which show the potential to generate photon pairs with broadband entanglement.

41. UNIFYING QUANTUM MACHINE LEARNING MODELS: THEORY AND PRACTICAL IMPLICATIONS

SOFIENE JERBI

Machine learning algorithms based on parametrized quantum circuits are prime candidates for near-term applications on noisy quantum computers. In this direction, various types of quantum machine learning models have been introduced and studied extensively. Yet, our understanding of how these models compare, both mutually and to classical models, remains limited. In this work, we identify the first constructive framework that captures all standard models based on parametrized quantum circuits: that of linear quantum models. In particular, we show using tools from quantum information theory how data re-uploading circuits, an apparent outlier of this framework, can be efficiently mapped into the simpler picture of linear models in quantum Hilbert spaces. Furthermore, we analyze the experimentally-relevant resource requirements of these models in terms of qubit number and amount of data needed to learn. Based on recent results from classical machine learning, we prove that linear quantum models must utilize exponentially more qubits than data re-uploading models in order to solve certain learning tasks, while kernel methods additionally require exponentially more data points. Our results provide a more comprehensive view of quantum machine learning models as well as insights on the compatibility of different models with NISQ constraints.

42. FALLING THROUGH MASSES IN SUPERPOSITION: QUANTUM REFERENCE FRAMES FOR INDEFINITE METRICS

VIKTORIA KABEL

The current theories of quantum physics and general relativity on their own do not allow us to study situations in which the gravitational source is quantum. Here, we propose a strategy to determine the dynamics of objects in the presence of mass configurations in superposition, and hence an indefinite spacetime metric, using quantum reference frame (QRF) transformations. Specifically, we show that, as long as the mass configurations in the different branches are related via relative-distance-preserving transformations, one can use an extension of the current framework of QRFs to change to a frame in which the mass configuration becomes definite. Assuming covariance of dynamical laws under quantum coordinate transformations, this allows to use known physics to determine the dynamics. We apply this procedure to find the motion of a probe particle and the behavior of clocks near the mass configuration, and thus find the time dilation caused by a gravitating object in superposition.

43. A ONE-NODE QUANTUM REPEATER

OLIVIER MORIN

Optical fibers have been a game changer for modern communication. However, the losses cannot be compensated in the quantum regime, limiting most quantum communications to hundreds of kilometers. The quantum repeater is a promising solution to this problem as it improves the rate-versus-distance scaling by dividing the link into subsegments. Although it has been proposed more than two decades ago, it remains an important experimental challenge. Here, using two atoms of 87Rb coupled to a high finesse cavity, we implemented a complete repeater protocol. By using repeated generation of atom-photon entanglement but independently for each atom, one ends up with entanglement between Alice and atom A, and Bob with atom B. Eventually entanglement swapping on the two atoms, create a pair of entangled qubits shared by Alice and Bob. However, thanks to the independent repeat-until-success strategy the rate-versus-distance scaling is improved by a factor two compared to direct transmission. In addition, we maintained an error below 11% which guarantees an unconditional security. S. Langenfeld et al., Phys. Rev. Lett. 126, 230506 (2021)

44. TUNABLE DIPOLE-DIPOLE INTERACTIONS IN AN ARRAY OF LEVITATED NANOPARTICLES

UROS DELIC

The field of quantum optomechanics aims to exploit light-matter interaction in order to realize macroscopic quantum states of massive solid-state mechanical objects. Within optomechanics, optically levitated dielectric nanoparticles have emerged as a promising platform for tests of fundamental physics, development of novel sensing techniques or investigation of complex non-equilibrium physics. Optical trapping provides unique possibilities for quantum state preparation, for example through engineering of arbitrary optical potentials or by using free-fall for long coherence times. I will discuss recent experimental advances in levitated optomechanics, such as motional quantum ground state preparation [1] and the observation of non-reciprocal optical interactions between two nanoparticles [2]. The rapidly developing optical control toolbox will allow us to generate a fully programmable trap array of levitated nanoparticles in the quantum regime. This will enable the realization of large-scale entanglement and investigation of novel phases of collective mechanical states, which is a fundamentally hard task for other optomechanical systems.

[1] U. Delic et al., Science 367, 892 (2020) [2] Rieser et al., Science 377, 987 (2022)

71. ENTANGLING MICROWAVE WITH OPTICAL PHOTONS

RISHABH SAHU

Connecting future quantum computers over a large distance needs optical links between physical qubits that are often realized in the gigahertz domain inside a cryogenic environment. Microwave-optics transduction would rely on two transduction cycles to transfer information between physically separated qubits. Better transfer state fidelities can be achieved via direct quantum teleportation based on microwave-optical entanglement. However, so far such entangled states could not be prepared due to the incompatibility of low loss superconductivity and high energy optical photons that prevented the required ultra-low noise conditions. Here, we demonstrate the deterministic preparation of an entangled microwave-optical state in the continuous variable domain that is squeezed by 0.7 dB below the vacuum level. This result is achieved in a triply resonant, pulsed electro-optic interconnect in a millikelvin environment.

45. MICROWAVE SINGLE PHOTON SOURCE USING LANDAU-ZENER TRANSITIONS

SIDDHI KHAIRE

As efforts towards quantum communication advance, the need for single photon sources becomes imminent. Due to the extremely low energy of a single microwave photon, efforts to build single photon sources and detectors in the microwave range are relatively recent. We plan to use a Cooper Pair Box (CPB) that has a 'sweet-spot' where the two energy levels have minimal separation. Moreover, these qubits have fairly large anharmonicity making them close to ideal two-level systems. If the external gate voltage of these qubits is varied rapidly while passing through the sweet-spot, due to Landau-Zener effect, the qubit can be excited almost deterministically. The rapid change of the gate control voltage through the sweet spot induces a non-adiabatic population transfer from the ground to the excited state. The qubit eventually decays into the emission line emitting a single photon. The advantage of this set-up is that the qubit can be excited without any coherent microwave excitation, thereby effectively increasing the usable source efficiency. Since the probability of a Landau-Zener transition can be made almost close to unity by appropriate design of parameters, this source behaves as an on-demand source of single microwave photons. Such a system has so far not been implemented and would find many applications in the areas of quantum optics, quantum computation as well as quantum communication.

46. TRANSFORMATIONS IN QUANTUM NETWORKS VIA LOCAL OPERATIONS ASSISTED BY FINITELY MANY ROUNDS OF CLASSICAL COMMUNICATION

TRISTAN KRAFT

Beyond future applications, quantum networks open interesting fundamental perspectives, notably novel forms of quantum correlations. In our work we discuss quantum correlations in networks from the perspective of the underlying quantum states and their entanglement. We address the questions of which states can be prepared in the so-called triangle network, consisting of three nodes connected pairwise by three sources. We derive necessary criteria for a state to be preparable in such a network, considering both the cases where the sources are statistically independent and classically correlated. This shows that the network structure imposes strong and non-trivial constraints on the set of preparable states, fundamentally different from the standard characterization of multipartite quantum entanglement. We show that the theory of quantum coherence provides powerful tools for analyzing this problem. For that, we demonstrate that a recently proposed approach to network correlations based on covariance matrices can be improved and analytically evaluated for the most important cases. Finally, the second part of the poster deals with the characterization of indistinguishability of photons in linear interferometers, boson sampling, and the connnection to shadow tomography.

47. GENERATIVE NEURAL NETWORKS FOR CONSTRUCTING LOCAL HIDDEN VARIABLE MODELS AND SEPARABLE STATES

TAMÁS KRIVÁCHY

The advent of deep neural networks has led to numerous applications in the scientific domains. Here, we study their use in studying Bell-nonlocality and entanglement. In particular, we use neural networks to explicitly represent local hidden variable models or separable quantum states. Thus, we can optimize over such states, for example to find closest separable states or closest local distributions to given target states/distributions. These numeric works have led to a number of interesting insights in Bell nonlocality on networks with independent sources. For example, the neural network conjectured nonlocality for a distribution (which has since been proved!), and assisted in developing the first experimentally friendly proposal of nonlocality in the triangle network, and more recently, conjectured the first interpretable inequality for the triangle network. I will present these results on Bell-nonlocality, together with some results on separability, with a more generic outlook on how neural networks can be used in quantum foundations, particularly in parametrizing classical objects, and showing how we can use this as an indication that with quantum, we go Beyond the Classical.

48. OVERCOMING NOISE IN VARIATIONAL QUANTUM COMPUTATIONS VIA SUPERPOSITION OF TRAJECTORIES

MARIUS KRUMM

Recently, in the field of quantum causality, several schemes were discovered that use superposition of trajectories of inputs to re-enable noisy channels to transmit information. In this work, we apply these schemes to quantum channels that are supposed to perform variational quantum computations, but are too noisy to actually do so. We show that the dependence on the variational parameters can be partially restored in various cases. Furthermore, some of these schemes depend on how the noise arises from an interaction with an environment, allowing to infer some information about the environment.

49. MULTIPARTITE ENTANGLEMENT DISTRIBUTION VIA SEPARABLE SYSTEMS

ALESSANDRO LANEVE

A fundamental requirement towards the realization of effective quantum networks and realistic quantum communication protocols is the capability of distribute entanglement among remote nodes, with a high degree of reliability. Hence, it would be advisable to generate entanglement right before its employment, because of its fragility. This is often not the case, since the distribution of entanglement usually requires entanglement with a carrier system that is transmitted among the parties. Nevertheless, it has been demonstrated that two systems can be entangled also via local interactions with a carrier system that does not get entangled with them at any time during the protocol. We conceive a strategy for entanglement distribution via separable systems that works for any number of distant nodes. This protocol can be used to generate diverse entanglement patterns with great flexibility and we demonstrate that it results in the production of genuine multipartite entanglement, while the carrier system is always kept in a separable state with respect to the nodes. We also present some possible experimental implementation proposals.

50. MIXED MAGIC STATES FOR MATCHGATE COMPUTATIONS

MARC LANGER

Circuit-based universal quantum computation can be achieved by supplementing non-universal gate sets, such as Clifford gates and matchgates, with additional resources. One example of such a resource is given by the combination of so-called magic input states and adaptive measurements. Whereas all pure magic states for matchgate circuits have been characterized recently, the question of which mixed states can be considered magic is largely unanswered. An explicit protocol for the purification of certain four-qubit states was proposed by S. Bravyi [Phys. Rev. A 73 (042313), 2006]. We extend this result by showing that other mixed states can also be purified to the 4-qubit GHZ state, which is magic for matchgate computations.

51. SCALABLE SET OF REVERSIBLE PARITY GATES FOR INTEGER FACTORIZATION

MARTIN LANTHALER

Classical microprocessors operate on irreversible gates, that, when combined to AND, half-adder and full-adder operations, execute complex tasks such as multiplication of integers. We introduce parity versions of all components of a multiplication circuit. The parity gates are reversible quantum gates based on the recently introduced parity transformation and build on ground-space encoding of the corresponding gate logic. Using a quantum optimization heuristic e.g. an adiabatic quantum computing protocol - allows one to quantum mechanically reverse the process of multiplication and thus factor integers, which has important applications in cryptography. Our parity approach builds on nearest neighbor parity ZZZ[Z] constraints equipped with local fields, able to encode the logic of a binary multiplication circuit in a modular and scalable way.

52. FLOQUET THEORY FOR A FAST AND HIGH FIDELITY PARAMETRIC-TWO-QUBIT GATE

CAMILLE LE CALONNEC

A major challenge in realizing scalable quantum computers is the optimization of two-qubit entangling gates. The realization of high-fidelity quantum gates involves a multitude of parameters governing important properties of the system, such as the gate rate, leakage, spurious interactions etc. One therefore needs to carefully choose these parameters to optimize the gate speed while minimizing unwanted cross-Kerr interaction. Numerically, this can be a resource intensive process as it implies simulating the gate dynamics for each set of device parameters. We present a method based on Floquet theory to extract the interaction rates without having to run full dynamical simulations. We apply this technique to a new two-qubit entangling parametric gate that we developed in collaboration with the Houck lab at Princeton. First experimental results show the realisation of a sqrt(iSWAP) gate in 13 ns with 99.8% fidelity.

53. CHARACTERIZATION OF STATE TRANSFORMATIONS WITHIN ENTANGLEMENT CLASSES CONTAINING PERMUTATION-SYMMETRIC STATES & IDENTIFICATION OF ISOLATION-FREE CLASSES

NICKY KAI HONG LI

Since local operations and classical communication (LOCC) cannot generate entanglement, the existence of LOCC transformations among a set of states imposes a partial order on their degree of entanglement. It was known that generic pure multipartite qudit states are isolated (i.e. cannot be obtained from nor transformed to any state) under LOCC. For non-generic states, only the stochastic LOCC (SLOCC) classes of n-qubit GHZ and W states are known to be isolation-free (i.e. contain no isolated states) to date. The natural question to ask is if there are other SLOCC classes that are also isolation-free since we expect these states to have special entanglement properties. In [PRA 105, 032458 (2022)], we found (weakly) isolated states in all SLOCC classes that contain permutation-symmetric states of which the stabilizers were characterized, except the n-qubit GHZ and W classes. We subsequently discover a new isolation-free SLOCC class, which is the class of 3-qutrit totally antisymmetric state, and prove that the class of n-qudit totally antisymmetric state contain (weakly) isolated states for all n>=4. Currently, we are investigating whether (weakly) isolated states exist in every SLOCC class of n-qubit states for all n>=4, except of the GHZ and W classes. If this is true, it will provide strong evidence that the GHZ and W classes are the only n-qubit SLOCC classes that are isolation-free.

54. MULTIDIMENSIONAL ENTANGLEMENT GENERATION WITH MULTICORE OPTICAL FIBERS

ITALO MACHUCA

Trends in photonic quantum information follow closely the technical progress in classical optics and telecommunications. In this regard, advances in multiplexing optical communications channels have also been pursued for the generation of multi-dimensional quantum states (qudits), since their use is advantageous for several quantum information tasks. One current path leading in this direction is through the use of space-division multiplexing multi-core optical fibers, which provides a new platform for efficiently controlling path-encoded qudit states. Here we report on a parametric down-conversion source of entangled qudits that is fully based on state-of-the-art multi-core fiber technology. The source design uses multi-core fiber beam splitters to prepare the pump laser beam as well as measure the generated entangled state, achieving high spectral brightness while providing a stable architecture. In addition, it can be readily used with any core geometry, which is crucial since widespread standards for multi-core fibers in telecommunications have yet to be established. Our source represents an important step towards the compatibility of quantum communications with next-generation optical networks.

55. PROSPECTS OF SIDEBAND COOLING OF A MECHANICAL RESONATOR USING A TRANSMON QUBIT IN C-QED SETUP

SOURAV MAJUMDER

Hybrid devices based on superconducting qubits have emerged as a promising platform for controlling the quantum state of macroscopic resonators. The nonlinearity added by qubit mode can be a valuable resource in this direction. Here we analyze mechanical mode coupled to a flux-tunable transmon in c-QED setup. The coupling between mechanical and transmon qubit can be implemented by modulation of SQUID inductance, as demonstrated in the recent experiments. The qubit state readout can be performed in a traditional c-QED setup. In such a tri-partite system, we analyze the steady-state occupation of the mechanical mode when all three modes are dispersively coupled. We can achieve a large coupling between mechanical and qubit modes with a flux bias in the dispersive regime of cavity and qubit. We use quantum noise and Lindblad formalism to show that cooling mechanical mode to the ground state is possible. To address the issue of mechanical readout in the dispersive regime, we introduce a pump signal in cavity frequency. Due to cross-Kerr interaction, it allows recording of thermal motion. Our initial experimental results show the prospects of measurements of thermomechanical motion while maintaining a large coupling between qubit and mechanics. Our theoretical modeling suggests that such a cross-Kerr interaction can be a valuable resource for the quantum control of the mechanical resonator.

56. ENTANGLING SINGLE ATOMS OVER 33 KM TELECOM FIBRE

POOJA MALIK

Quantum repeaters will allow scalable quantum networks, which are essential for large scale quantum communication and distributed quantum computing. A crucial step towards a quantum repeater is to achieve heralded entanglement between stationary quantum memories over long distances. To this end, we present results demonstrating heralded entanglement between two Rb-87 atoms separated by 400 m line-of-sight, generated over telecom fiber links with a length up to 33 km [1]. To entangle the two atoms, we start with entangling the spin state of each atom with the polarization state of a photon in each node via synchronized excitations during the spontaneous decay. The emitted photons (780 nm) are then converted to the low loss telecom S band (1517 nm) via a polarisation preserving frequency conversion to overcome high attenuation loss in optical fiber over longer distances [2]. Long fibre links guides these photons to a middle station where a Bell-state measurement swaps the entanglement to the atoms. Finally, the atomic states are analysed after a delay that allows for two-way communication between the nodes and the BSM over the respective fibre length. We observe loss in fidelity for longer fibre links due to the limited atomic coherence time.

[1] T.van Leent et al., Nature 607, 69–73 (2022) [2] T.van Leent et al., Phys. Rev. Lett. 124, 010510 (2020)

57. CERTIFICATION OF A NONPROJECTIVE QUDIT MEASUREMENT USING MULTIPORT BEAMSPLITTERS

DANIEL MARTÍNEZ ARIAS

Generalised quantum measurements go beyond the textbook concept of a projection onto an orthonormal basis in Hilbert space. They are not only of fundamental relevance but have also an important role in quantum information tasks. However, in scenarios where the quantum devices are not assumed to be characterised beyond their degrees of freedom, it is highly demanding to certify that an experiment harvests the advantages made possible by generalised measurements, especially beyond the simplest, qubit, system. Here, we use state-of-the-art multicore optical fiber technology to build multiport beamsplitters and faithfully implement a seven-outcome generalised measurement in a four-dimensional Hilbert space with a fidelity of 99.7. We apply it to perform a basic quantum communication task and demonstrate a success rate that cannot be simulated in any conceivable quantum protocol based on standard projective measurements on quantum messages of the same dimension. Our approach, which is compatible with modern photonic platforms, showcases an avenue for faithful and high-quality implementation of genuinely nonprojective quantum measurements beyond qubit systems.

58. SHAPING THE INTERATOMIC INTERACTIONS IN A MULTIMODE CAVITY: FROM NON-RIGID SUPERSOLID TO DROPLETS

NATALIA MASALAEVA

The ultracold atoms in optical lattices serve as a versatile platform for quantum simulations and can assist in the realization of a supersolid state of matter. However, the conventional periodic optical potentials do not support non-trivial elastic deformations, since they are infinitely stiff. The supersolid implemented in such systems turns out to be impervious to the phononic excitations that determine thermodynamic properties and elastic response of real materials. In our work we show how to overcome this shortcoming and implement a nonrigid supersolid by coupling a Bose gas into many longitudinal modes of a ring cavity. Depending on the number of pumped modes and two-body contact-interaction strength, we identify five distinct phases characterized by different values of calculated order parameters (density contrast, inverse participation ratio, superfluid fraction, and cavity-mode amplitudes): normal phase, rigid supersolid, non-rigid supersolid or elastic supersolid, insulating droplets, and a single droplet. The realization of a novel supersolid with phononic excitations in a cavity-QED setup paves an alternative way to answer open fundamental questions in condensed-matter physics.

59. HIERARCHY OF QUANTUM NON-GAUSSIAN CONSERVATIVE MOTION

DARREN MOORE

Mechanical quantum systems embedded in an external nonlinear potential currently offer the first deep excursion into quantum non-Gaussian motion. The Gaussian statistics of the motion of a linear mechanical quantum system, characterised by its mass and a linear-and-quadratic potential, possess a limited capacity to reduce noise in nonlinear variables. This limitation induces thresholds for noise reduction in nonlinear variables beyond which linear mechanical oscillators can- not pass. Squeezing below the thresholds for such variables is relevant for the implementation of nonlinear mechanical devices, such as sensors, processors or engines. First however, quantum non- Gaussian conservative motion must be identified in experiments with diverse nonlinear potentials. For this purpose, we provide sufficient criteria for quantum non-Gaussian motional states in con- servative systems based on the observation of squeezing in nonlinear variables. We further extend these criteria to a hierarchy able to recognise the quantum non-Gaussian motion induced via diverse nonlinear potentials through their various capacities to produce nonlinear squeezing.

60. METROLOGY-ASSISTED ENTANGLEMENT DISTRIBUTION IN NOISY QUANTUM NETWORKS

SIMON MORELLI

Entanglement shared between multiple users, for instance within a quantum network, is a crucial resource that allows one to overcome the restrictions of local operations and classical communication and thereby to implement classically impossible tasks. In this work we propose a novel strategy for the distribution of high-dimensional multipartite entanglement within noisy quantum networks with subsequent probabilistic state conversion. For certain types of noise the conversion can be carried out without the exact knowledge of the noise, which opens the possibility to use unsuccessfully converted copies for the estimation of the channel. Without sacrificing potentially good copies for this task, this protocol thus gains an advantage over comparable strategies in terms of the obtained number of copies close to the desired target state. We show the potential of the proposed strategy in a concrete example, where we consider the distribution of generic GHZ-type states in a network in the presence of local dephasing noise.

61. A QUANTUM-LOGIC GATE ON REMOTE MATTER QUBITS

OLIVIER MORIN

Nowadays quantum computation units are developed as monolithic hardware e.g., ions in the same trap, superconducting qubits on the same chip, Rydberg atoms in the same vacuum chamber etc. Although those platforms offer significant possibilities in quantum computing they will inevitably hit a scalability limit. A contrario, a modular architecture will not suffer such a limitation. A promising example is for instance single qubit modules interconnected via photonic qubits travelling through a network of optical fibers. Our recent work demonstrated such an approach with the cavity quantum electrodynamics toolbox. Our module made of single atoms of 87Rb are coupled too high finesse optical cavities. In this scenario, local quantum gates are routinely realized with Raman or microwave manipulations. Hence, we showed that the missing non-local quantum-logic can be mediated by a single photon travelling from one module to the other: we realized a CNOT gate between the two modules separated by a 60m-long optical fiber. Severin Daiss et al., Science 371, 614-617 (2021)

62. MULTI-PHOTON ENTANGLED STATES FROM A SINGLE ATOM

PHILIP THOMAS

Controlling systems of many qubits while minimizing the effects of decoherence and crosstalk is one of the main challenges for the development of new quantum technologies. Optical photons interact weakly with the environment and thus naturally evade these issues. During the last decades many experiments on photonic entanglement were carried out using spontaneous parametric down conversion. However, the underlying process is intrinsically probabilistic and thus poses a practical limit on the size of entangled states one can generate. In order to avoid this obstacle, we use a single Rubidium atom in an optical cavity as an efficient photon source. Single photons are emitted sequentially while the atomic spin qubit mediates entanglement between them. We show that by tailored single-qubit operations on the atomic state we generate Greenberger-Horne-Zeilinger (GHZ) states of up to 14 photons and linear cluster states of up to 12 photons. A combined source-to-detection efficiency of 43% leads to a coincidence rate orders of magnitude higher than the previous state-of-the-art. Our work represents a step towards scalable measurement-based quantum computing and communication.

63. SOLVING RANK CONSTRAINED SEMIDEFINITE PROGRAMS IN POLYNOMIAL TIME

JOSHUA MORRIS

We describe an iterative procedure that computes feasibility semidefinite programs over linearly constrained rank one projectors. We prove that the rank constraint adds at most an O(n^3) factor to the complexity of the original problem before proceeding to demonstrate its application in currently open quantum infomration problems including unitary optimisation, unistochastic matrix classification and a restricted version of the quantum marginal problem.

64. TRAPPING AND COOLING OF LARGE TWO-DIMENSIONAL ION CRYSTALS IN A MONOLITHIC PAUL TRAP

TUOMAS OLLIKAINEN

Over the last decade, linear strings of ions have proved remarkably successful platform for quantum simulations. Scaling the system up to two-dimensional (2D) ion crystals would allow a higher number of qubits in the system and inherently enable quantum simulations of more complicated 2D spin systems. Here, we experimentally realize stably-trapped 2D ion crystals with up to 91 particles in a monolithic Paul trap, and characterize the stability of the planar crystal configurations. We implement electromagnetically-induced-transparency (EIT) cooling and show that it can be used to ground-state cool the out-of-plane modes of the 2D ion crystal. Finally, we measure the mean phonon numbers and heating rates of the 2D ion crystal, and implement a novel method for multi-ion thermometry based on the initial dynamics of the motional sidebands.

65. QUANTUM HAMILTON EQUATIONS FOR NELSON'S STOCHASTIC MECHANICS: A VIEW ON FOUNDATIONS AND APPLICATIONS

WOLFGANG PAUL

In 1966 E. Nelson derived the Schrödinger equation as the Hamilton-Jacobi formulation of a time-reversible, i.e. energy conserving in the mean, diffusion process. Two further physical assumptions enter into this: the diffusion coefficient is given by $\hbar/m$ and Newton's second law is valid for the average acceleration along the irregular Brownian path. This is sufficient to formulate a quantum analytical mechanics [1] in parallel to classical analytical mechanics, which has been achieved over the last 50 years. We recently derived Quantum Hamilton Equations (QHE) [2] in this framework and showed how to use them to solve quantum problems without recourse to the Schrödinger equation. This makes the Schrödinger equation one but not the complete description of quantum phenomena. We will discuss applications of this approach to the prediction of tunnelling times [3] and their distribution and to the motion of the electron in the hydrogen atom [4].

[1] M. Beyer, W. Paul, Universe 7, 166 (2021) [2] J. Köppe, W. Grecksch, W. Paul, Ann. Phys. (Berlin) 529, 1600251 (2017) [3] J. Köppe, M. Patzold, W. Grecksch, W. Paul, J. Math. Phys. 59, 062102 (2018) [4] M. Beyer, M. Patzold, W. Grecksch, W. Paul, J. Phys. A.: Math. Theor. 52, 165301 (2019)

66. TESTING THE NONCLASSICALITY OF SPACETIME: WHAT CAN WE LEARN FROM BELL-BOSE ET AL.-MARLETTO-VEDRAL EXPERIMENTS?

DAMIÁN PITALÚA-GARCÍA

The Bose et al.-Marletto-Vedral (BMV) experiment [S. Bose et al., Phys. Rev. Lett. 119, 240401 (2017); C. Marletto and V. Vedral, Phys. Rev. Lett. 119, 240402 (2017)] aims to prove that spacetime is nonclassical by observing entanglement generated by gravity. However, local hidden variable theories (LHVTs) can simulate the entangled correlations. We propose [A. Kent and D. Pitalúa-García, Phys. Rev. D 104, 126030, 2021] to extend the entanglement generated by the BMV experiment to distant quantum particles in a Bell experiment. Violating a Bell inequality would rule out LHVTs, providing a stronger proof of the nonclassicality of spacetime than the BMV proposal.

67. MULTIPHOTON AND SIDE-CHANNEL ATTACKS IN MISTRUSTFUL QUANTUM CRYPTOGRAPHY

DAMIÁN PITALÚA-GARCÍA

Mistrustful cryptography includes important tasks like bit commitment, oblivious transfer, coin flipping, secure computations, position authentication, digital signatures and secure unforgeable tokens. Practical quantum implementations presently use photonic setups. In many such implementations, Alice sends photon pulses encoding quantum states and Bob chooses measurements on these states. In practice, Bob generally uses single-photon threshold detectors, which cannot distinguish the number of photons in detected pulses. Also, losses and other imperfections require Bob to report the detected pulses. Thus, malicious Alice can send and track multiphoton pulses and thereby gain information about Bob's measurement choices, violating the protocols' security. Here (M. Bozzio, A. Cavailles, E. Diamanti, A. Kent and D. Pitalúa-García, PRX Quantum 2, 030338, 2021), we provide a theoretical framework for analyzing such multiphoton attacks, and present known and new attacks. We illustrate the power of these attacks with an experiment, and study their application to earlier experimental demonstrations of mistrustful quantum cryptography. We analyze countermeasures based on selective reporting and prove them inadequate. We also discuss side-channel attacks where Alice controls further degrees of freedom or sends other physical systems.

68. PRACTICAL QUANTUM TOKENS WITHOUT QUANTUM MEMORIES AND EXPERIMENTAL TESTS

DAMIÁN PITALÚA-GARCÍA

Unforgeable quantum money tokens were the first invention of quantum information science, but remain technologically challenging as they require quantum memories and/or long-distance quantum communication. More recently, virtual "S-money" tokens were introduced. These are generated by quantum cryptography, do not require quantum memories or long-distance quantum communication, and yet in principle guarantee many of the security advantages of quantum money. Here (A. Kent, D. Lowndes, D. Pitalúa-García and J. Rarity, npj Quantum information 8, 28, 2022), we describe implementations of S-money schemes with off-the-shelf quantum key distribution technology, and analyse security in the presence of noise, losses, and experimental imperfection. Our schemes satisfy near-instant validation without cross-checking. We show that, given standard assumptions in mistrustful quantum cryptographic implementations, unforgeability and user privacy could be guaranteed with attainable refinements of our off-the-shelf setup. We discuss the possibilities for unconditionally secure (assumption-free) implementations.

69. SIMULATING QUBIT CORRELATIONS WITH FINITE COMMUNICATION

MARTIN JOHANNES RENNER

Bell's famous theorem shows that quantum correlations cannot be reproduced by local hidden variables. However, it is possible to simulate quantum entanglement when the parties are allowed to transmit some classical communication. For the simplest case of projective measurements on two maximally entangled qubits, Toner and Bacon (Phys. Rev. Lett. 91, 187904, 2003) proved that already a single bit is sufficient. At the same time, somehow counterintuitively, all previously known protocols to simulate non-maximally entangled qubits require more resources. In this work, however, we present a protocol to simulate two weakly entangled qubits with a single bit and another protocol to simulate every entangled qubit pair with a single trit. We also study the simulation cost of other scenarios. More precisely, we present a protocol that uses only two bits to simulate a qubit channel in any prepare and measure scenario even when the measurements are allowed to be positive operator-valued measurements (POVMs). For that case, previously known protocols required an unbounded amount of communication in the worst case. We show that this protocol is optimal by presenting a task in which qubits can outperform trits. Finally, we use this result to generalize the protocol of simulating entangled qubit pairs to the scenario where the parties are allowed to perform POVMs.

70. AVOIDING BARREN PLATEAUS USING CLASSICAL SHADOWS

STEFAN SACK

Variational quantum algorithms (VQAs) are promising algorithms for achieving quantum advantage on near-term devices. The quantum hardware is used to implement a variational wave function and measure observables, whereas the classical computer is used to store and update the variational parameters. The optimization landscape of expressive variational ansätze is however dominated by large regions in parameter space, known as barren plateaus (BPs)1-3, with vanishing gradients which prevents efficient optimization. In this work, we propose a general algorithm to avoid BPs in the initialization and throughout the optimization. To this end, we define a notion of weak barren plateaus (WBP) based on the entropies of local reduced density matrices. The presence of WBPs can be efficiently quantified using recently introduced shadow tomography4 of the quantum state with a classical computer. We demonstrate that avoidance of WBPs suffices to ensure sizable gradients in the initialization. In addition, we demonstrate that decreasing the gradient step size, guided by the entropies allows avoiding WBPs during the optimization process. This paves the way for efficient BP free optimization on near-term devices.

[1] McClean et al., Nat Commun 9, 4812 (2018) [2] Cerezo et al., Nat Commun 12, 1791 (2021) [3] Holmes et al., PRX Quantum 3, 010313 (2022) [4] Huang et al., Nat Phys 16, 1050-1057 (2020)

72. A VARIATIONAL QUANTUM ADIABATIC ALGORITHM

BENJAMIN SCHIFFER

We present a protocol for preparing the eigenstate of a Hamiltonian using distributed quantum computation. Using two copies of an initial state, we show that our protocol can amplify the dominant eigenstate with logarithmic dependence on the desired inverse precision. If the initial state does not have a dominant eigenstate, the protocol prepares an arbitrary eigenstate. Our protocol requires the ability to implement controlled unitary evolution of the Hamiltonian. The dependence on the spectral gap is optimal and the dependence on initial state properties is comparable to quantum phase estimation. We put the method in context with existing literature and show possible applications for combining the protocol with the adiabatic algorithm or other methods for eigenpath traversal.

73. EXPERIMENTAL QUANTUM STATE DISCRIMINATION USING THE OPTIMAL FIXED RATE OF INCONCLUSIVE OUTCOMES STRATEGY

ESTEBAN SEPÚLVEDA GÓMEZ

The problem of non-orthogonal state discrimination requires to find optimal scenarios to doing this task. We experimentally investigate the optimal discrimination of two non-orthogonal states considering a Fixed Rate of Inconclusive Outcomes (FRIO). FRIO strategy interpolates unambiguous and minimum error discrimination by adjusting the rate of inconclusive outcomes. We will show an experimental scheme that performs the optimal FRIO measurement for any pair of non-orthogonal states generated with arbitrary a priori probabilities. We implement it upon qubit states encoded in the polarization mode of single photons generated in the spontaneous parametric down-conversion process. Moreover, we resort to a double-path Sagnac interferometer to perform a three-outcome non-projective measurement required for the discrimination task, showing excellent agreement with the theoretical prediction. This experiment provides a practical toolbox for a wide range of quantum state discrimination strategies using the FRIO scheme, which can greatly benefit quantum information applications and fundamental studies in quantum theory.

74. MULTIPHOTON INTERFERENCE WITH PARTIALLY DISTINGUISHABLE PHOTONS

BENOIT SERON

The ability to interfere many single photons is a cornerstone for the development of photonic technologies as well as for demonstrations of quantum computational advantage via the Boson Sampling problem. An important source of noise in multiphoton interference experiments is that the input photons do not have perfectly identical wave-functions, i.e. they are partially distinguishable. We present different contributions regarding multiphoton interference with partially distinguishable photons. First, we show the counterintuitive role of partial distinguishability in boson bunching phenomena, revealing how partially distinguishable photons may bunch more than indistinguishable ones. Second, we present new tools for the efficient validation of boson samplers which can be used to distinguish whether the input photons are ideal bosons or partially distinguishable ones. Finally, we present the recently created Julia package BosonSampling.jl that regroups generic tools for the exploration of fundamental and practical questions about multiphoton interference with partially distinguishable photons.

75. GKP CODE STABILIZATION WITH ROBUST ANCILLA ERROR SUPPRESSION

CHRISTIAN SIEGELE

The GKP code allows for generic error-correction of a qubit encoded in a harmonic oscillator. Recent experiments have demonstrated the stabilization of the code manifold based on Rabi interactions with an ancillary two-level system. However, these schemes suffer from uncorrectable logical flips triggered by ancilla relaxation errors during the interaction. We propose a protocol to stabilize the GKP code in a target mode by mapping its error syndromes to an ancillary GKP mode via a quadrature-quadrature interaction. In contrast to previously proposed schemes, coupling to solely one ancilla quadrature allows tailoring the ancilla state and its preparation accordingly to ensure a strong suppression of back-propagating errors to the target mode. The error-syndrome information is retrieved and the ancilla efficiently re-initialized using similar techniques demonstrated in the recent GKP experiments. For realistic system parameters, numerical simulations confirm the robust suppression of ancilla induced logical errors and show an enhancement of the logical qubit lifetime by an order of magnitude beyond the break-even point.

76. TOWARDS LARGE-SCALE ENTANGLEMENT-ENHANCED INTERFEROMETRY

RAFFAELE SILVESTRI & HAOCUN YU

We report experimental progress in detecting Earth’s rotation with an optical fiber ring Sagnac interferometer using two-photon polarization-entangled NOON states of light. We have proposed and realized a fiber optic gyroscope which encodes the Sagnac phase in the polarization of light and performs polarization state tomography. Measurements with continuous-wave light have already verified that the sensitivity and stability levels of our fiber interferometer are sufficient to resolve a Earth rotation-induced phase shift of 4 mrad. By injecting NOON-states we aim to show super-resolution and work towards demonstrating quantum-enhancement in a large-scale interferometer. This will also allow us to probe for the first time Earth's rotation influence on photon entanglement, opening the door to proposed experiments using interferometry to measure frame dragging and other general-relativistic effects on quantum systems.

77. DAEMONIC ERGOTROPY AND NON-CLASSICAL THERMALIZATION VIA QUANTUM SWITCH

KYRYLO SIMONOV

We characterize the impact that the application of two maps in a quantum-controlled order has on the process of work extraction via unitary cycles and its optimization. The control is based on the quantum switch model that applies maps in an order not necessarily compatible with the underlying causal structure and, in principle, can be implemented experimentally. First, we show that the activation of quantum maps through the quantum switch model always entails a non-negative gain in ergotropy compared to their consecutive application. We also establish a condition that the maps should fulfill in order to achieve a non-zero ergotropic gain. We then perform a thorough analysis of maps applied to a two-level system and provide general conditions for achieving a positive gain on the incoherent part of ergotropy. Our results are illustrated with several examples and applied to qubit and d-dimensional quantum systems. In particular, we demonstrate that a non-zero work can be extracted from a system thermalized by two coherently controlled reservoirs.

78. A QUANTUM CAUSAL PERSPECTIVE OF MEASUREMENT-BASED QUANTUM COMPUTATION

ISAAC SMITH

The failure of classical causal models to fully capture the intricacies of quantum phenomena has spurred the development of the more general framework of Quantum Causal Models (QCMs). Both formalisms treat and manipulate probability distributions arising from observations of, and interventions on, a system of interest, however these notions are much more subtle in the quantum case: in general a measurement non-trivially disturbs the quantum system. This property of quantum measurements can be beneficial as demonstrated, for example, by measurement-based quantum computation (MBQC) where projective measurement on a highly entangled state give rise to a universal model of quantum computation. In this work, we connect MBQC and QCMs by defining two quantum causal models related to the former. With these models, we commence investigations into two applications of interest, namley black box MBQC and blind quantum computing, from a causal perspective.

80. ARTIFICIAL QUANTUM STATES OF LIGHT FROM SINGLE PHOTONS

PETR STEINDL

Engineering of quantum states from individual single photons is an important form of preparation of multi-photon entangled quantum states, such as cluster [1] or graph states for quantum computing and communication. Similarly, if multiple single-photon streams are combined using beam splitters, photonic states with a more complex structure in photon number (Fock) basis can be prepared [2]. Here, we experimentally create engineered quantum states with tunable photon statics including approximate weak coherent states with g(2)(0) → 1 [4]. These states are synthesized from a random continuous high-quality single-photon stream produced by an InAs quantum dot in an integrated optical micropillar cavity [3]. By using quantum interference of at least 3 photons in a free-space optical delay loop that acts as a quantum memory and enables entangling single photons produced at different times. Contrary to coherent states, our artificial states are more complex, containing also quantum entanglement of photons.

[1] Istrati, Pilnyak, et al., Nat. Commun. 11, 5501 (2020). [2] Loredo, et al., Nat. Photonics 13, 803 (2019). [3] Steindl, et al., Phys. Rev. Lett. 126, 143601 (2021). [4] Snijders, et al., Phys. Rev. Appl. 9, 031002 (2018).

81. ON-CHIP TIME-BIN ENTANGLEMENT USING BRAGG-REFLECTION WAVEGUIDES AS PHOTON-PAIR SOURCES

HANNAH THIEL

To prepare quantum communication for its large-scale commercialization, sources for quantum states of light have to be made smaller and better integrable. A promising candidate are Bragg-reflection waveguides (BRWs) made from the AlGaAs platform. Their strong χ(2) nonlinearity enables photon pair production in the telecom wavelength range via parametric down-conversion. We improved the fabrication recipe for BRWs and achieved a reduction in sidewall roughness by a factor of three leading to a decrease in optical loss coefficient of 0.14/mm compared to previous samples. The BRW is end-face coupled to a polymer chip which hosts passive optical components for pump suppression and separation of the photons in a pair. The photons are then relayed to time-bin analysis stations which correspond to Alice and Bob in a quantum key distribution scenario. There, the photons are sent through on-chip asymmetric Mach-Zehnder interferometers and detected by superconducting nanowire detectors. The impossibility to distinguish between photons created in the two-time bins is evidenced by interference in the coincidence counts between the two photons detected at Alice’s and Bob’s site. The visibility of this interference fringe is measured by varying the phase in one of the interferometers.

82. COHERENT CANCELLATION OF TUNNELING AMPLITUDE IN A SQUEEZED KERR OSCILLATOR

JAYAMEENAKSHI VENKATRAMAN

Superconducting circuits is well-suited to revisit driven dissipative nonlinear dynamics in novel parameters relevant to modern technologies beyond fundamental interest. In this work, we measure dynamical quantum tunneling in the classically forbidden region of a driven Kerr oscillator. We show that the tunneling matrix element is fully suppressed when the frequency of the drive is detuned from the oscillator at even multiples of Kerr. At these dynamical sweet spots, we further measure a sharp increase in the logical lifetime of the qubit encoded in the oscillator. The sharp increase is a consequence of the exact degeneracies of the Floquet spectrum which we also independently measure.

83. ENHANCING QUANTUM CRYPTOGRAPHY WITH QUANTUM DOT SINGLE-PHOTON SOURCES

MICHAL VYVLECKA

Quantum cryptography harnesses quantum light, in particular single photons, to provide security guarantees that cannot be reached by classical means. For each cryptographic task, the security feature of interest is directly related to the photons' non-classical properties. Quantum dot-based single-photon sources are remarkable candidates, as they can in principle emit deterministically, with high brightness and low multiphoton contribution. Here, we show that these sources provide additional security benefits, thanks to the tunability of coherence in the emitted photon-number states. Generating either mixed or coherent states of light allows for enhanced performance of many quantum cryptography applications. We identify the optimal optical pumping scheme for the main quantum-cryptographic primitives, and benchmark their performance with respect to Poissondistributed sources such as attenuated laser states and down-conversion sources. The studied primitives include quantum key distribution (BB84, decoy, twin-field), strong coin flipping, unforgeable quantum tokens and bit commitment. The presented results will guide future developments in solid-state and quantum information science for photon sources that are tailored to quantum communication tasks.

84. INEQUALITIES WITNESSING COHERENCE, NONLOCALITY AND CONTEXTUALITY

RAFAEL WAGNER

Quantum coherence, nonlocality, and contextuality have been identified as key resources for quantum advantage in tasks involving metrology, communication, and computation. In this work we introduce a new graph approach to derive classicality inequalities that, depending on how we associate quantum preparations and measurements to vertices and edges, represent bounds on both non-contextual and coherence-free models. We prove that our approach i) recovers all non-contextuality inequalities obtainable using the exclusivity graph approach; ii) generalizes recently proposed basis-independent coherence witnesses using overlaps, and iii) provides witnesses of preparation contextuality. We describe an algorithm to find all such classicality inequalities, and use it to analyze many simple scenarios, explicitly recovering most well-known inequalities such as the original Bell inequality from the minimal scenario, the Clauser-Horne-Shimony-Holt inequality and the Klyachko-Can-Binicio ˘glu-Schumovsky inequality. These new inequalities may represent a novel technique for analyzing when coherence in experimental set-ups such as in interference experiments or in light-harvesting complexes can be witness of higher-level nonclassicality provided by the notion of quantum contextuality.

85. PREPARATION OF TENSOR NETWORK STATES

ZHI-YUAN WEI

First, we discuss two implementations to sequentially generate photonic matrix product states (MPS), one based on a Rydberg atomic array [1], and another based on a microwave cavity dispersively coupled to a transmon [2]. Then, we introduce plaquette projected entangled-pair states (P-PEPS)[3], a class of states in a lattice that can be generated by applying sequential unitaries acting on plaquettes of overlapping regions. They satisfy area-law entanglement and possess long-range correlations. We identify a subclass that can be more efficiently prepared in a radial fashion and that contains the family of isometric tensor network states. We also show how such subclass can be efficiently prepared using an array of photon sources [2]. Then we propose and study an adiabatic path to prepare short-range correlated MPS and PEPS [4]. This path guarantees a gap and allows for efficient numerical simulation. In 1D we show that adiabatic preparation can be much faster than the sequential preparation. We also apply the method to the 2D AKLT state on the hexagonal lattice, and show that it can be prepared very efficiently for relatively large lattices.

[1] ZYW et al., PR RESEARCH 3, 023021 (2021) [2] ZYW et al., PRA 105, 022611 (2022) [3] ZYW et al., PRL 128, 010607 (2022) [4] ZYW et al., in preparation.

86. QUANTUM ALGORITHMS WITH SUPERCONDUCTING QUBITS COUPLED TO HIGH Q COAXIAL CAVITIES

IAN YANG

High Q coaxial cavities have shown high single photon quality factors of 0.5 X 109 [1]. Such a low-loss cavity is especially useful as a common quantum bus for multiple qubits or for encoding quantum information, using it as a bosonic qubit. Here, we present our platform for coupling transmon qubits to a high Q cavity. We use high purity niobium in a quarter-wave coaxial seamless design [2]. We use electro-discharge machining and buffer chemical polishing for a smooth surface that reduces losses in the cavity. A flux hose allow us to apply magnetic field inside the superconducting coaxial cavity [3]. The flux hose also allows for fast flux tuning. Our in-house assembled hoses are ideally suited for fast flux bias lines in 3D superconducting architectures.We are also incorporating a bandpass filter that will act as a modular Purcell filter replacing the readout SMA pin. By combining these ingredients, we build a platform for interacting mutli-qubit systems for quantum information processing. Additionally, the multi-dimensional Hilbert space of the cavity is a suitable for hardware efficient encoding for quantum error correction.

[1] P. Heidler et al., Phys. Rev. Appl., vol. 16, no. 3 (2021) p. 034024 [2] M. Reagor et al.,Phys. Rev. B, vol. 94, no. 1 (2016) p. 014506 [3] O. Gargiulo et al., Appl. Phys. Lett., vol. 118, no. 1 (2021) p. 012601

87. A ROBUST ATOMIC QUBIT ENCODING FOR LONG-DISTANCE ENTANGLEMENT DISTRIBUTION

YIRU ZHOU

Heralded entanglement between distant quantum memories is one of the building blocks for quantum networks, which, will enable secure quantum communication and distributed quantum computing. To this end, we developed a quantum link employing entanglement shared between two independently trapped Rb-87 atoms - located in buildings 400 m apart. The atoms can be entangled over fibre links with a length up to 33 km, enabled by mitigating attenuation losses in the longer fibres via polarization-preserving quantum frequency conversion [1]. Decoherence of the atomic states reduces the observed atom-atom state fidelity for long fibre lengths. To increase the memory storage time, we implemented a state-selective Raman transfer scheme [2] to transfer the qubit into one with significantly lower sensitivity to fluctuating magnetic fields. We achieved an improvement of the coherence time from around 330 μs to 7 ms. The new qubit encoding enabled for atom-photon entanglement distribution over 101 km optical fibre with a fidelity of higher than 70.8%, which is limited by single photon detector dark counts. Our results pave the way towards city-to-city scale quantum network links.

[1] T. van Leent et al., Nature 607, 69-73 (2022) [2] M. Körber et al., Nat. Photonics 12, 18-21 (2018)

88. A GENERAL-PURPOSE PHOTONIC ONE-WAY QUANTUM COMPUTER

FELIX ZILK

Various general-purpose quantum systems have become accessible via the internet, e.g., IBM's publicly available superconducting devices. Current hardware implements circuit-based models, annealers, or continuous-variable computing systems. The discrete-variable one-way model of quantum computing is of special interest in photonic systems, although not limited to them. Quantum processors based on this model are not yet available to users. Here we evaluate five key components for the implementation of a remotely programmable, general-purpose photonic one-way quantum computer.

89. JORDAN-WIGNER TRANSFORMATION FOR SPIN 1

NICOLÁS MEDINA SÁNCHEZ

The Jordan-Wigner transformation for spin 1/2 has been used remarkably to diagonalise systems of 1D spin chains mapping spin ladder operators for 2-level systems into fermionic creation-annihilation operators. The fact that for higher spins there is no analog for the spin ladder operators in the creation-annihilation algebras for standard quantum statistics makes impossible to generalise the transformation in that way. Here we make a generalisation for spin 1 using a new type of quantum statistics. These statistics also allow generalisations for higher spins opening the possibility of new diagonalisation schemes for condensed matter physics.