Quantum Information and Quantum Computing

This session has been organised in collaboration with the SFB BeyondC.

Tuesday, 31.08.2021, Room F

Time	ID	**Quantum Information and Quantum Computing I** *Chair: Martin Ringbauer, Universität Innsbruck*
16:30	**501**	**Coherent control of a symmetry-engineered multi-qubit dark state in waveguide quantum electrodynamics** *Maximilian Zanner [1], Romain Albert, Mathieu Juan, Gerhard Kirchmair, Stefan Oleschko, Tuure Orell, Christian Schneider [2], Matti Silveri* *[1] University of Innsbruck, [2] University of Oldenburg* The coherence properties of an atom or superconducting qubit strongly depend on the electromagnetic environment. In waveguide QED the qubit is strongly coupled to a continuous mode spectrum, thus it decays rapidly. Collective effects between multiple qubits can be utilized to generate subradiant states that decouple from the dissipative waveguide environment. In our experiment we strongly couple two pairs of transmon qubits to the fundamental mode of a rectangular waveguide. We show that the decay of the dark state is strongly suppressed, exceeding the waveguide-limited lifetimes of individual qubits by two orders of magnitude. Our experiment presents a step towards implementations of quantum many-body simulations in open quantum systems.
16:45	**502**	**Three-dimensional quantum walks of correlated photons** *Robert Keil [1], Max Erhardt [2], Lukas Maczewsky [2], Christoph Dittel [3], Matthias Heinrich [2], Alexander Szameit [2]* *[1] University of Innsbruck, [2] University of Rostock, [3] University of Freiburg* We introduce a previously unidentified paradigm for the direct experimental realization of excitation dynamics of three-dimensional networks by exploiting the hybrid action of spatial and polarization degrees of freedom of photon pairs propagating in coupled waveguide circuits with tailored birefringence. The photons exhibit Hong-Ou-Mandel-like interference simultaneously in both degrees of freedom. In a cubic graph, their interference pattern follows a recently predicted suppression law, imposed by the graph's underlying symmetry. Moreover, the presented platform can serve as a testbed for the experimental exploration of multiparticle quantum walks on complex, highly connected graphs, suggesting a route towards exploring the dynamics of fermions in integrated quantum photonics.
17:00	**503**	**Quantum-DFT Embedding Algorithm for Electronic Structure Calculations** *Max Rossmannek [1,2], Panagiotis Barkoutsos [1], Pauline Ollitrault [1], Valery Weber [1], Vladimir Rybkin [2], Jürg Hutter [2], Ivano Tavernelli [1]* *[1] IBM Quantum, IBM Research - Zurich, 8803 Rüschlikon* *[2] Department of Chemistry, University of Zürich, Winterthurerstrasse 190, 8057 Zürich* In the near future, molecular simulations will be aided by quantum computer-assisted calculations which have the potential to target systems intractable for classical computers. However, since the resources offered by near term quantum computers are still limited, it is necessary to investigate hybrid quantum-classical computational schemes. In our recent work (J. Chem. Phys. 154, 114105, 2021), we rapidly scaled up such quantum-assisted simulations by means of embedding the quantum electronic structure calculation into a classically computed environment at the DFT level of theory. In this talk, I will present an extension of our work, interfacing the open source framework for quantum computing, Qiskit, with the highly parallelized classical code CP2K.

17:15	**504**	**Cavity optomechanics implemented using levitating superconductors and Josephson microwave circuits** *Philip Schmidt [1], Markus Aspelmeyer [2], Joachim Hofer [2], Gerard Higgings [3], Michael Trupke [2], Stefan Minniberger [2], Dominik Ilk [2]* *[1] Austrian Academy of Science, [2] University of Vienna, [3] Chalmers University* Experimental investigation of quantum mechanics with heavy objects (> m_{planck} ~20 μg) has not been achieved. It requires the combination of decoupling the quantum object from environmental influences, while remaining high control of it, a challenge increasing with the mass of the object. To achieve these, we implement the approach of superconducting microspheres in a magnetic field trap, allowing for a mass independent levitation. To reach sufficiently high coupling rates we inductively couple the mechanical motion to superconducting circuits to enable quantum states of motion in a completely new regime of masses. In my talk I will discuss prospects and challenges of the envisioned approach along with the current status of our experiment.
17:30	**505**	**Entanglement in Quantum Networks** *Tristan Kraft [1], Sébastien Designolle [2], Cornelia Spee [1], Xiao-Dong Yu [3], Christina Ritz [3], Nicolas Brunner [2], Otfried Gühne [3], Marcus Huber [4]* *[1] University of Innsbruck, [2] University of Geneva, [3] University of Siegen, [4] IQOQI Vienna* Advances in quantum information processing and technologies lead to promising developments towards a quantum network. The latter would feature local quantum processors exchanging information and entanglement via quantum links, enabling, for instance, long-distance quantum communication. The focus of this contribution is to investigate quantum correlations in networks from the point of view of entanglement. We will discuss the possibilities and limitations for entanglement generation, given the constraints of the network topology. We discuss networks featuring independent or classically correlated sources, and derive conditions for a quantum state to be preparable in the network. This shows that network structures impose strong and nontrivial constraints on the set of preparable quantum states.
17:45	**506**	**Trapped ions in optical microtraps** *Matteo Mazzanti [1], Thomas Feldker [2], Rene Gerritsma [1], Rima Schüssler [1], Zhenlin Wu [1]* *[1] University of Amsterdam, [2] University of Innsbruck* We present progress on an experimental setup in which we aim to implement two-dimensional ion-crystals in a Paul trap. We will use novel optical microtraps to manipulate the phonon spectrum of the crystal. This in turn allows us to engineer the spin-spin interactions. In particular, the pinning of a single ion can be used to create short-range spin-spin interactions. In 2D crystals, this can be used to quantum simulate spin Hamiltonians on a kagome lattice, which, at low energies, are described by emergent gauge fields. Combining addressed ion operations with phonon-mode engineering, it should be feasible to equip the quantum simulator with a complete set of operations.
18:00	**507**	**SPTO under Quantum Channels** *Caroline de Groot [1], Alex Turzillo [1], Norbert Schuch [2]* *[1] MPI for Quantum Optics, [2] University of Vienna* This talk will discuss the stability of symmetry protected topological (SPT) order under noisy channels. It has been shown that SPT order is destabilized by simple models of noise, collapsing the classification of SPT phases into a single trivial phase, even if the noise is symmetric in the usual sense. We introduce a stronger symmetry condition on channels that ensures that they preserve SPT order.

18:15	**508**	**Operation of a microfabricated 2D ion trap array** *Marco Valentini [1], Silke Auchter [1,2], Philip Holz [1,3], Matthias Dietl [1,2], Gerald Stocker [2], Clemens Rössler [2], Elmar Aschauer [2], Yves Colombe, Philipp Schindler [1], Thomas Monz [1,3], Rainer Blatt [1,3]* *[1] University of Innsbruck, [2] Infineon Technologies, [3] Alpine Quantum Technologies* We investigate scalable surface ion traps for quantum simulation and quantum computing. We developed a micro-fabricated surface trap consisting of two parallel linear-trap arrays with 11 trapping sites each. We demonstrate trapping and shuttling of multiple ions, and form square and triangular ion-lattice configurations with up to six ions. We characterize stray electric fields and measure ion heating rates between 131(13) and 470(50) phonons/s in several trapping sites [1]. Furthermore, the design of the trap array allows for tuning of the inter-ion distance across the lattice, which we will use to demonstrate motional coupling of ions in neighboring sites. [1] Philip C. Holz et al., Adv. Quantum Technol. 3.11 (2020)
18:30	**509**	**Identifying and reducing errors in a trapped ion system** *Claire L. Edmunds, Universität Innsbruck, Quantum Optics and Spectroscopy, Department of Experimental Physics, Technikerstraße 25a, 6020 Innsbruck* Quantum information experiments are advancing rapidly with realisations of real-time quantum error correction [1], demonstrations of variational quantum computing, for example, in metrology [2], and explorations of novel topological phases [3]. Underpinning these advancements is the requirement for high fidelity gates with low and uncorrelated errors between gates and qubits [4]. However, as machines are scaled up in both the number of qubits and algorithm length, it becomes increasingly challenging to keep error rates low in hardware alone. Quantum control enables the suppression of errors to a level that exceeds limitations set by physical hardware when using primitive gate implementations. I will demonstrate the identification, reduction and homogenisation of errors across a qubit register, reducing overhead and pre-conditioning the system for quantum error correction. In addition, I will identify potential applications of these techniques in current quantum information experiments. [1] C. Ryan-Anderson et al., arXiv:2107.07505 (2021); [2] C. Marciniak et al., arXiv:2107.01860 (2021); [3] C. Senko et al., Phys. Rev. X 5, 021026 (2015); [4] D. Greenbaum and Z. Dutton, Quantum Sci. Technol. 3 015007 (2018)
18:45		
19:00		***Postersession with Apéro***

Wednesday, 01.09.2021, Room F

Time	ID	**QUANTUM INFORMATION AND QUANTUM COMPUTING II** *Chair: Lee Rozema, Universität Wien*
14:00	**511**	**Quantum Photonics for Quantum Machine Learning and Secure Computing** *Philip Walther, Faculty of Physics, University of Vienna* This talk presents recent experimental demonstrations that use integrated nanophotonic processors for various quantum computations such as quantum machine learning and in particular reinforcement learning, where agents interact with environments by exchanging signals via a communication channel. We show that this exchange allows boosting the learning of the agent. Another experiment underlines the feasibility of photonic quantum system for so-called probabilistic one-time programs that allow for secure classical computation tasks. As outlook I will discuss technological challenges for the scale up of photonic quantum computers, and our group's current work for addressing some of those.

14:30	**512**	**Protocols in quantum networks: communication and beyond** *Stefanie Barz, University of Stuttgart* In this talk, I will discuss applications of quantum networks going beyond quantum key distribution. I will show that quantum networks can be used to perform distributed computing, both classical and quantum. Furthermore, I will present a recent experiment that shows quantum communication in a multipartite network and allows – besides security in the communication – keeping the identities of the participating parties secure. I will conclude with a discussion of experimental challenges in realizing advanced networked quantum protocols.
15:00	**513**	**Nuclear spins in a semiconductor quantum dot: through the looking-glass, and what we found there** *Mete Atature, Cavendish Laboratory, University of Cambridge* Optically active spins in solids are often considered prime candidates for scalable and feasible quantum-optical devices. Numerous material platforms including diamond, semiconductors, and atomically thin 2d materials are investigated, where each platform brings their own advantages along with their challenges. Semiconductor quantum dots are the current state-of-the-art for optical properties such as tuneability, brightness and indistinguishability. Their nickname "artificial atom" was coined historically to highlight how similar they can be to isolated single atoms, but in fact they are far from the realisation of a simple two-level system. The inherently mesoscopic nature of a quantum dot leads to a multitude of dynamics between spins, charges, vibrations, and light. In particular, it offers a unique realisation of a tripartite interface between light, a single proxy qubit (electron spin) and an isolated spin ensemble (nuclei). Ability to control these constituents and their mutual interactions creates opportunities to realise an optically controllable ensemble of ~50,000 spins. In this talk, I will present the two-decade journey from treating the quantum dot nuclei as noise to the observation of their collective magnon modes and eventually to their tuneable quantum correlations, all witnessed via a single electron spin driven by light.
15:30	**514**	**Solving Optimization Problems on Near Term Quantum Devices** *Wolfgang Lechner, Universität Innsbruck* Algorithms that run on near term quantum devices will be a decisive step towards applications of quantum computers. In this talk I will focus on optimization problems and how to encode and solve them on quantum devices. I will present the parity mapping and algorithms that make use of it. In particular, the talk will focus on encoding of optimization problems with higher-order terms and side conditions in the form of hard constraints.
16:00		
16:30		***Coffee Break***
		QUANTUM INFORMATION AND QUANTUM COMPUTING III *Chair: Philipp Schindler, Universität Innsbruck*
17:00	**521**	**Informational restrictions in quantum correlations** *Armin Tavakoli [1], Emmanuel Zambrini Cruzeiro [2], Jonatan Brask [3], Nicolas Gisin [4], Nicolas Brunner [4]* *[1] ÖAW, [2] Université libre de Bruxelles, [3] Technical University of Denmark, [4] University of Geneva* We investigate the relationship between quantum correlations and the communication of quantum bits of information. We go beyond standard qubits and instead consider a more general notion of informational restriction which makes no reference to the dimension of Hilbert space. We show how to characterise such informationally restricted quantum correlations and how they qualitatively go beyond standard qubits. Finally, we discuss how this concept both accommodates and provides an alternative perspective on well-known concepts such as Bell nonlocality, quantum contextuality and quantum dense-coding.

17:30	**522**	**Experimental demonstration of a quantum model learning agent on the NV-centre platform** *Sebastian Knauer [1], Raffaele Santagati [2], Antonio A. Gentile [2], Brian Flynn [2], Nathan Wiebe [3], Anthony Laing [2], Christopher E. Granade [4], Stefano Paesani [5], John G. Rarity [2]* *[1] University of Vienna,* *[2] Quantum Engineering Technology Labs, University of Bristol,* *[3] University of Washington,* *[4] Quantum Architectures and Computation Group, Microsoft Research,* *[5] ntum Engineering Technology Labs, University of Bristol* Developing novel quantum technology exhibits the challenge of their efficient characterisation. We introduce and experimentally demonstrate a methodology to automatically formulate and select Hamiltonian models, learning the most appropriate in reproducing the observed system's dynamics. Here, we propose and experimentally demonstrate the quantum model learning agent (QMLA), a Bayesian approach based upon the generation and exploration of alternative, parametrised models; and additional a frequentist approach. To test our methodology, we use the Hamiltonian describing a nitrogen-vacancy-centre electron spin interacting with a spin bath.
17:45	**523**	**Quantum Variational Learning of the Entanglement Hamiltonian** *Christian Kokail* *Institute for Quantum Optics and Quantum Information Innsbruck, Austrian Academy of Sciences* In this talk I will describe a quantum-classical variational protocol for learning the structure of the Entanglement Hamiltonian (EH) in Quantum Simulation experiments. In this approach, spatial deformations of the many-body Hamiltonian, physically realized on the quantum device, serve as an efficient variational ansatz for a local EH. On-device spectroscopy of the learned Hamiltonian provides a tool to characterize complex quantum phases. I will discuss advantages over classical learning protocols and will provide prospects that Hamiltonian learning can serve as a tool for verifying quantum simulators in a regime inaccessible to classical simulations.
18:00	**524**	**Optimal metrology with variational quantum circuits on trapped ions** *Christian Marciniak [1], Thomas Feldker [1], Ivan Pogorelov [1], Philipp Schindler [1], Thomas Monz [1], Rainer Blatt [1], Raphael Kaubrügger [2], Denis Vasilyev [2], Rick van Bijnen [2], Peter Zoller [1,2]* *[1] University Innsbruck, [2] IQOQI Innsbruck* Ensembles of cold atoms and ions excell in metrology and quantum information processing. This opens the opportunity to utilize tailored, programmable entanglement generation to approach the 'optimal quantum sensor'. Here we report first quantum enhancement in metrology beyond squeezing through low-depth, variational quantum circuits searching for optimal input states and measurement operators. We perform entanglement-enhanced Ramsey interferometry using a Bayesian approach to stochastic phase estimation tailored to the sensor platform. We verify the performance by both directly using theory predictions of optimal parameters, and performing online feedback optimization to 'self-calibrate' the variational parameters. We find that variational circuits outperform classical, and direct spin squeezing strategies under realistic noise and imperfections.
18:15	**525**	**Quantum algorithms for quantum dynamics: a performance study on the spin-boson model** *Alexander Miessen [1], Pauline Ollitrault [1,2], Ivano Tavernelli [1]* *[1] IBM Research - Zürich, [2] Laboratory of Physical Chemistry, ETH Zürich* Variational quantum algorithms (VQAs) have become an indispensable tool for noisy near-term quantum computation, enabling small-scale simulations on present-day hardware. So far, however, their success was mainly limited to optimization problems. The go-to method for dynamics remains Trotter-evolution, relying on deep circuits and thus hampered by the substantial limitations of available quantum technology. Despite the development of VQAs for dynamics, their capabilities and feasibility are yet to be assessed. In this study, we investigate the potential of this technique by simulating a spin-boson model in different physical regimes and under varying levels of hardware noise. Furthermore, we compare to Trotter-evolution and make scaling predictions for both algorithms.

18:30	**526**	**Coherence Equality and Communication in a Quantum Superposition** *Flavio del Santo, IQOQI Vienna* I will introduce a “coherence equality” that, in the spirit of Bell’s inequalities, can be used to discriminate between classical and quantum resources. This equality is satisfied by any classical communication (localized carrier), but is violated when the carrier is in a quantum superposition of communication directions. This implies that the classical success probability of a certain communication task is always equal to 1/2. Yet, we develop two simple quantum schemes that systematically deviate violate the coherence equality. Such a violation can also be exploited as an operational way to witness spatial quantum superpositions without requiring the use of an interferometer, but only by means of spatially separated local measurements.
18:45	**527**	**Macroscopically nonlocal quantum correlations** *Miguel Gallego, Borivoje Dakić, University of Vienna* 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 work 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.
19:00		
19:30		***Public Lecture***

Thursday, 02.09.2021, Room F

Time	ID	**Quantum Information and Quantum Computing IV** *Chair: Markus Arndt, Universität Wien*
	~~501~~	*cancelled*
14:30	**515**	**Learning to measure: A new adaptive approach to extract information in quantum algorithms for near-term quantum computers.** *Sabrina Maniscalco, Department of Physics and Astronomy, University of Turku* Just like their classical counterparts, quantum algorithms require a set of inputs, provided for example as real numbers, and a list of operations to be performed on some reference initial state. Unlike classical computers, however, information is stored in a quantum processor in the form of a wavefunction, thus requiring special procedures to read out the final results. In fact, it is in general neither possible nor convenient to fully reconstruct this quantum state, so that useful insights must be extracted by performing specific observations. Unfortunately, the number of measurements required for many popular applications is known to grow unsustainably large with the size of the system, even when only partial information is needed. This is for example the case for the so-called Variational Quantum Eigensolver, which is based on the reconstruction of average energies. In this talk I will discuss a novel scheme to tackle this problem. We employ a generalised class of quantum measurements that can be iteratively adapted to minimize the number of times the target quantum state should be prepared and observed. As the algorithm proceeds, it reuses previous measurement outcomes to adjust its own settings and increase the accuracy of subsequent runs. We make the most out of every sample by combining all data produced while fine-tuning the measurement into a single, highly accurate estimate of the energy, thus decreasing the expected runtime by several orders of magnitude. Furthermore, all the measurement data contain complete information about the state: once collected, they can be reused again and again to calculate any other property of the system without additional costs.

15:00	**532**	**Quantum verification with few copies** *Borivoje Dakić* *University of Vienna, Quantum Optics, Quantum Nanophysics and Quantum Information* As quantum technologies advance, the ability to generate increasingly large quantum states has experienced rapid development. In this context, the verification of large entangled systems represents one of the main challenges in the employment of such systems for reliable quantum information processing. Though the most complete technique is undoubtedly full tomography, the inherent exponential increase of experimental and post-processing resources with system size makes this approach infeasible at even moderate scales. Other methods aiming at probing only certain properties of the system such as entanglement detection via witness operators generally demand much less effort, but still consume large number of copies for reliable estimates, which may go beyond the reach of the large-scale regime. For this reason, there is currently an urgent need to develop novel techniques that surpass these limitations. In this talk I will review novel techniques focusing on a fixed number of resources (sampling complexity), and thus prove suitable for systems of arbitrary dimension. Specifically, a probabilistic framework requiring at best only a single copy for entanglement detection is reviewed, together with the concept of selective quantum state tomography, which enables the estimation of arbitrary elements of an unknown state with a number of copies that is low and independent of the system's size. These hyper-efficient techniques define a dimension demarcation for partial tomography and opens a path for novel applications.
15:30	**533**	**Enhancing quantum phase fluctuations in qubits with geometric superinductance** *Matilda Peruzzo, Andrea Trioni, Johannes Fink, Farid Hassani* *Institute of Science and Technology Austria* Characteristic impedance in superconducting quantum circuits determines whether the ground state wavefunction is dominated by charge or phase fluctuations. The crossover occurs at R_Q = 6.45 kΩ above which the charge fluctuations are suppressed below $2e^-$. Most interesting is the behavior of the Josephson junction (JJ), which acts as a non-linear inductor at low impedance and as a non-linear capacitor in the opposite limit. We explore this limit by shunting the JJ with a geometric inductor formed a superconducting high density planar coil. This element maintains a single uninterrupted wavefunction and offers high reproducibility, linearity and the ability to couple qubits magnetically.
16:00	**534**	**Observing emergent hydrodynamics with trapped ions** *Manoj Kumar Joshi [1], Florian Kranzl [1], A. Schuckert [2], Rainer Blatt [3], M. Knap [2], I. Lovas [2], C. Maier [4], Christian F. Roos [3]* *[1] Institute for Quantum Optics and Quantum Information, Innsbruck* *[2] Department of Physics and Institute for Advanced Study, TU München, DE-85748 Garching* *[3] Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, AT-6020 Innsbruck* *[4] AQT, Technikerstrasse 17, AT-6020 Innsbruck* Physicists have been fascinated by the non-equilibrium dynamics of quantum systems for a long time. Microscopic details are relevant at the early stage of the time dynamics where the system has just begun thermalizing. However, at the onset of thermal equilibrium, the dynamics are governed by symmetries and topology, and at this stage, classical hydrodynamics is expected to emerge. In this talk, we will report experimental measurements of quantum to classical hydrodynamics cross-over observed in a long-range interacting spin system containing 51 trapped ions. By varying the range of our spin-spin interaction and by measuring the spatio-temporal correlations, we will show normal diffusion to superdiffusion transport, described by Lévy flights.
16:30		***Coffee Break***

Time	ID	**Quantum Information and Quantum Computing V** *Chair: Christian Marciniak, Universität Innsbruck*
17:00	**541**	**Towards broadband photon pair generation in ultra-thin carbon nanotube films** *Alessandro Trenti, Philipp K. Jenke, Irati Alonso Calafell, Kimmo Mustonen, Lee Rozema, Philip Walther* *University of Vienna, Boltzmanngasse 5, 1090 Vienna* In ultra-thin media, the phase-matching condition for nonlinear optical processes, such as four-wave mixing (FWM), relaxes. We characterize the resulting broadband biphoton states by stimulated emission tomography and present progress towards photon pair generation in ultra-thin carbon nanotube films. Our 200 nm thick single-walled carbon nanotube film (much smaller than the pump wavelength of around 810 nm) imposes energy conservation as the only requirement in the nonlinear interaction. The absence of phase-matching entails 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 more than 50 THz. This result shows the potential to generate photon pairs with broadband entanglement with application in particular in the field of quantum communication, such as demonstration of entanglement distribution.
17:15	**542**	**Entanglement detection in NISQ devices** *Jose Carrasco, University of Innsbruck* I will discuss the recent proposal of a set of experimentally accessible conditions for detecting entanglement in mixed states based on comparing moments of the partially transposed density operator. The union of all inequalities reproduces the Peres-Horodecki criterion. Exploiting symmetries can help to further improve their detection capabilities and the estimation of the inequalities is based on local random measurements in single-copy experiments. We show how to include the experimentally relevant situation of non-identical (but independent) copies (drifts) in the analysis and derive error bounds and confidence intervals as a function of the number of performed measurements.
17:30	**543**	**Interference as an information-theoretic game** *Sebastian Horvat, Borivoje Dakić, University of Vienna* The double slit experiment provides a demarcation between classical and quantum theory, while multi-slit experiments demarcate quantum and higher-order interference theories. In this work we show that these experiments pertain to a broader class of processes, which can be formulated as information-processing tasks. We provide a connection between the order of interference and the probabilities of successfully achieving the given tasks. Furthermore, we prove the order of interference to be additive under composition of systems both in classical and quantum theory. Finally, we extend our game formulation within the generalized probabilistic framework and prove that tomographic locality implies the additivity of the order of interference under composition.
17:45	**544**	**Witnessing Bell violations through probabilistic negativity** *Lukas J. Fiderer [2], Benjamin Morris [1], Ben Lang [1], Daniel Goldwater [1]* *[1] University of Nottingham, [2] University of Innsbruck* Bell's theorem shows that no hidden-variable model can explain the measurement statistics of a quantum system shared between two parties, thus ruling out a classical (local) understanding of nature. In this work we demonstrate that by relaxing the positivity restriction in the hidden-variable probability distribution it is possible to derive quasiprobabilistic Bell inequalities whose sharp upper bound is written in terms of a negativity witness of said distribution. This provides an analytic solution for the amount of negativity necessary to violate the CHSH inequality by an arbitrary amount, therefore revealing the amount of negativity required to emulate the quantum statistics in a Bell test.

18:00	**545**	**Smart Quantum Sensors:** **Neural-Network Heuristics for Adaptive Bayesian Quantum Estimation** *Lukas J. Fiderer [1], Jonas Schuff [2], Daniel Braun [3]* *[1] University Innsbruck, [2] University Oxford, [3] University Tübingen* Next-generation quantum sensors are expected to outperform classical sensors. Since the success of these quantum sensors depends on the efficient use of limited resources (such as probe states and coherence time), we introduce the paradigm of smart quantum sensors, i.e., quantum sensors which make autonomous adjustments in order to optimize the measurement precision and to save resources. A suitable framework for smart quantum sensors is provided by the adaptive Bayesian approach to parameter estimation. We train neural networks to become fast and strong experiment-design heuristics that are shown to outperform established heuristics for the technologically important example of frequency estimation of a qubit that suffers from dephasing.
18:15	**546**	**Towards implementations of device-independent quantum key distribution** *Pavel Sekatski, University of Geneva* In this talk, I will discuss the so-called device independent quantum key distribution (DIQKD) protocols – where all elements of the setup are analysed as black boxes. Contrary to standard QKD, the security of DIQDK does not rely on detailed quantum models of the devices and is proof against "quantum hacking". After a concise introduction I will present some ideas (noisy preprocessing, full-statistics analysis, random key measurements) that help bridging the gap between experimental requirements of DIQKD and current technological capabilities. Finally, we will discuss finite statistics analysis and the perspectives of long distance DIQKD based on SPDC generated entangled photons.
18:30	**547**	**Variational quantum policies for reinforcement learning** *Sofiene Jerbi [1], Casper Gyurik [2], Simon Marshall [2], Hans Jürgen Briegel [1,3], Vedran Dunjko [2]* *[1] University of Innsbruck, [2] University of Leiden, [3] University of Konstanz* Deep neural networks have had a profound impact on the field of reinforcement learning by achieving unprecedented performance in challenging decision-making tasks. Almost in parallel, the idea that variational quantum circuits could be used in quantum-classical machine learning systems started gaining increasing traction. Such hybrid systems have already shown the potential to tackle real-world tasks in supervised and generative learning, and recent works have established their provable advantages in artificial tasks. Yet, in the case of reinforcement learning, which is arguably most challenging, no proposal has been successful in solving standard benchmarking problems, nor has the potential of hybrid models been made clear. In this work, we resolve both questions.
18:45	**548**	**Emergence of biased errors in non-ideal photonic circuits** *Fulvio Flamini, University of Innsbruck* We discuss the emergence of a moderate biased error in non-ideal integrated photonic circuits. We investigate its correlation with properties of the optical paths, revealing potential issues for high-precision tests and optical implementations of machine learning.
19:00		***Transfer to Dinner***
19:30		***Conference Dinner***

Friday, 03.09.2021, Room F

Time	ID	QUANTUM INFORMATION AND QUANTUM COMPUTING VI *Chair: Fulvio Flamini, Universität Innsbruck*
11:15	551	**Universal quantum circuits for transforming unitary operations: Exponential advantages with adaptive strategies and the power of indefinite causality** *Marco Túlio Quintino [1], Daniel Ebler, Qingxiuxiong Dong, Atsushi Shimbo, Akihito Soeda, Mio Murao* *[1] Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna* Given a quantum gate implementing a unitary operation U without any specific description but its dimension, we present a universal quantum circuit that implements its inverse by making k uses of the given operation. We consider probabilistic and deterministic scenarios, in both cases, the performance exponentially approaches to a perfect implementation. The protocols employ an adaptive strategy, proven necessary for the exponential performance. Additionally, we discuss the power and limitations of indefinite causality by analysing the performance of processes where the use of the input-gates does not necessarily respect a definite causal order, a better performance may be obtained.
11:30	552	**Bell nonlocality with a single shot** *Mateus Araújo [1], Flavien Hirsch [1], Marco Túlio Quintino [1,2,3]* *[1] Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria* *[2] Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria* *[3] Department of Physics, Graduate School of Science, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-0033, Japan* In order to reject the local hidden variables hypothesis, the usefulness of a Bell inequality can be quantified by how small a p-value it will give for a physical experiment. Here we show that to obtain a small expected p-value it is sufficient to have a large gap between the local and Tsirelson bounds of the Bell inequality, when it is formulated as a nonlocal game. We develop an algorithm for transforming an arbitrary Bell inequality into an equivalent nonlocal game with the largest possible gap. We also present explicit examples of Bell inequalities with gap arbitrarily close to one, and show that this makes it possible to reject local hidden variables in a single shot, without needing to collect statistics.
11:45	553	**Operational reconstruction of quantum particle statistics** *Nicolas Medina Sanchez, Borivoje Dakić, University of Vienna* A fascinating fact about the collective behavior of indistinguishable quantum particles is the existence of only two types of statistics: bosonic and fermionic, characterized by the exchange symmetry of their associated quantum states. So far, all attempts to explain the origin of these symmetries resort on oblivious assumptions added to the abstract quantum formalism (e.g. dimensionality of space). Hereby we introduce an information-theoretic study of particle statistics in the space of abstract modes. We show that there are infinitely many statistics compatible with the unitary symmetry and the Fock space structure, with bosons and fermions as special cases which can be singled out by a set of simple operational principles.
12:00	554	**Duality between classical waves and particles** *Polina Pogrebinskaya, Borivoje Dakić, University of Vienna* Interference of single particles lies at the core of quantum mechanics. The most prominent demonstration of this effect is the double-slit experiment: a single experimental run indicates an experiment with single particles, however the statistics of repeated runs reassembles interference fringes. This is the source of the celebrated wave-particle duality. In this work we show that classical wave mechanics combined with the statistical detection model can completely reproduce quantum

		interference experiments with single particles. The recreation of quantum double-slit experiment using classical waves shows that the dual behaviour between waves and particles (at least its part described in this work) is not necessarily proof of a genuine quantum effect.
12:15	**555**	**Unruh effect for detectors in superposition of accelerations** *Luis C. Barbado [1], Esteban Castro-Ruiz [2], Luca Apadula [1], Časlav Brukner [1]* *[1] Universität Wien, [2] Ecole Polytechnique de Bruxelles* We consider the Unruh effect for a pointlike multilevel particle detector coupled to a massless real scalar field and moving in a quantum superposition of accelerated trajectories. The state of the detector excitations is, in general, not a mere mixture of the thermal spectrum characteristics of the Unruh effect for each trajectory with well-defined acceleration separately. For certain trajectories and excitations, and upon the measurement of the trajectory state, the state of the detector features in addition off-diagonal terms. The off-diagonal terms of these “superpositions of thermal states” are related to the distinguishability of the different possible states in which the field is left after its interaction with the detector.
12:30	**556**	**General Quantum Resource Theories:** **Maximal Resources, Catalytic Replication, and Consistent Measures** *Hayata Yamasaki [1,2], Kohdai Kuroiwa [1]* *[1] Photon Science Center, Graduate School of Engineering, The University of Tokyo, 7–3–1 Hongo, Bunkyo-ku, Tokyo 113–8656, Japan* *[2] IQOQI Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, AT-1090 Vienna* Quantum resource theories (QRTs) provide a unified framework for understanding quantum-mechanical properties, but physically well-motivated resources may possess structure whose analysis is mathematically intractable, such as non-uniqueness of maximally resourceful states, non-convexity, and infinite-dimensionality. We systematically study manipulation and quantification of resources in general QRTs under minimal assumptions. We prove general existence of maximally resourceful states. We also discover a novel phenomenon, catalytic replication of resources, where a resource state is infinitely replicable by free operations. Furthermore, we introduce and study notion of consistent resource measures to quantify resources without contradicting asymptotic-state-conversion rate. These establish unified foundation of QRTs applicable to physically well-motivated resources whose analysis can be mathematically intractable.
12:45	**557**	**Quantum Games** *Marcel Pfaffhauser, James Wootton, Fabio Scafirimuto, IBM Research-Zurich* The large interest from the general public combined with the need to develop the next generation of quantum workforce, set a new challenge for the quantum computing experts: educating a vast public of not expert. Several national and international initiatives focus on education and outreach targeting a broad range of audiences, from high school pupils to developers. In this scenario, Quantum Games represent an hands-on way to explain QC following the principle of “learning by doing”. We investigate several approaches to explain quantum concepts via games such as puzzles, boardgames, or, for the most creative, providing an user-friendly set of tools for people to make their own first quantum game.
13:00	**558**	**Symmetry in totally destructive many-particle interference** *Julian Münzberg [1], Christoph Dittel [2], Maxime Lebugle [3], Andreas Buchleitner [2], Alexander Szameit [4], Gregor Weihs [1], Robert Keil [1]* *[1] Universität Innsbruck, [2] Universität Freiburg, [3] Eulitha, [4] Universität Rostock* Quantum interference of indistinguishable bosons is indispensable for many quantum optical experiments. As in the famous Hong-Ou-Mandel effect, symmetry of the input state and symmetries in the scattering scenario can lead to destructive interference and the suppression of a large number of output events. The rules specifying which input-output combinations interfere totally destructively are summarized in so-called suppression laws. Here, we experimentally investigate the suppression law of the Jx unitary in a femtosecond laser-written waveguide structure with four photons emitted from a SPDC source. We show that totally destructive interference does not require mutual indistinguishability between all, but only between symmetrically paired particles, in agreement with recent theoretical predictions.

13:15	559	**Multi parameter Bayesian optimisation of the Mølmer-Sørensen gate** *Lukas Gerster [1], Fernando Martinez, Pavel Hrmo, Martin van Mourik, Benjamin Willhelm, Davide Vodola, Philipp Schindler [1], Thomas Monz [1], Markus Müller, Rainer Blatt [1]* *[1] Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck* One of the challenges of scaling up quantum processors is the optimization of the quantum gates, as each gate may require different control parameters. We developed and tested a fast protocol to automatically calibrate the entangling 2-qubit Mølmer Sørensen gate using Bayesian parameter estimation. Such a protocol promises to increase experimental uptime by decreasing the time needed for calibration, as well as allowing automated operation. Our protocol achieves a median infidelity of 0.13(1) % caused by miscalibration in 1200 + / - 500 experimental shots. This paves the way to decouple quantum circuits from their implementation on ion trap hardware, allowing operation by an end user without detailed knowledge of the physical realization.
13:30		***END***

ID	QUANTUM INFORMATION AND QUANTUM COMPUTING POSTER
561	**Quantum cryptography with highly entangled photons from GaAs quantum dots** *Christian Schimpf, Armando Rastelli, Saimon Covre da Silva, Daniel Huber, Barbara Lehner, Marcus Reindl, Santanu Manna, Michal Vyvlecka, Philip Walther, Johannes Kepler University Linz* Quantum-key distribution (QKD) is one of the most promising strategies for perfectly secure communication. Protocols based on entangled photon pairs are particularly attractive because of enhanced tolerance to losses and simplified generation of perfectly random secure keys. We use semiconductor-based sources of entangled photon pairs to implement QKD. Different from sources explored so far, quantum dots offer the triggered generation of near-unity entangled photon pairs and have the potential of generating photon pairs at GHz rates. We demonstrate continuous key generation for 13 hours between two buildings, connected via a 350 m single mode fiber with a resulting average error rate of 1.91 % and a key rate of 135 bits/s.
562	**Integrating cold atomic quantum simulators into Qiskit** *Laurin Fischer, Daniel J. Egger, IBM Research Zürich* Quantum systems based on cold atoms trapped in tweezer arrays are powerful analog simulators of the Hamiltonians they implement. Their experimental control has advanced to a point where they can be programmed to simulate a wide variety of physical systems. We report on a circuit- and gate-based description of cold atomic quantum simulators and how they integrate into a modern quantum computing software stack such as Qiskit. This paves the way to using non-standard quantum hardware beyond qubits for quantum information processing. As an example, we investigate variational algorithms for cold-atom-based simulators.
563	**Tensor and polynomial decompositions: making invariance and positivity explicit** *Andreas Klingler [1], Gemma de las Cuevas [1], Tim Netzer [2]* *[1] Institute for Theoretical Physics, University of Innsbruck* *[2] Department of Mathematics, University of Innsbruck* We develop a framework (based on a recently studied framework of tensor decompositions) to decompose multivariate polynomials into univariate polynomials in a general way, explicitly expressing the polynomial's invariance. If the polynomial is contained in some positivity cone (for example sum of squares polynomials), we introduce and characterise corresponding inherently positive decompositions. We show under which assumptions an invariant decomposition exists and provide explicit constructions for all cases. We prove that inherently positive decompositions can be arbitrarily more costly than unconstrained ones. Subsequently, we show that unconstrained decompositions cannot contain any computable local certificate of positivity for globally nonnegative polynomials by formulating an undecidable problem in this context.
566	**Cause and effect relations in interventional models** *Eleftherios-Ermis Tselentis, Ämin Baumeler, IQOQI Wien* While a lot of effort has been made to understand the physical cause and effect relations, a general characterization of the ones that are, at least in principle, admissible by a logically consistent theory is still missing. With this poster I present the main ideas and formalisms that are used in this research direction, focusing

	both on the quantum and the classical case. The presentation is especially focusing on the cyclic causal structures, which are of the most interest due to the corresponding interpretation as "time traveling" scenarios and the possible physical understanding through the theory of general relativity.
567	**Compact On-chip Vacuum Gap Transmon Qubits on Suspended SOI Membrane** *Martin Zemlicka, Elena Redchenko, Matilda Peruzzo, Farid Hassani, Shabir Barzanjeh, Johannes Fink* *Institute of Science and Technology Austria* Transmon qubits require a large shunt capacitance to decrease the sensitivity to charge fluctuations. It is usually realized by very large capacitor plates, which increase the coherence due to decreased coupling to parasitic losses localized in material interfaces but it lowers the achievable integration density and increases parasitic cross coupling. We achieve the large capacitance by narrow (≥ 100 nm) vacuum gaps micro-machined on suspended silicon membranes. The finger capacitor has 99.6 % of the electric field energy stored in vacuum and effective permittivity close to unity. The result is a compact on-chip transmon qubit with state of the art coherence per footprint area and losses limited by metal surface impurities.
568	**Local Transformations of Multiple Multipartite States** *David Gunn, Antoine Neven, Barbara Kraus, University of Innsbruck* Multipartite entanglement can be quantified by considering Local Operations assisted by Classical Communication (LOCC). However, for systems with fixed local dimensions, the partial order induced by LOCC is generically trivial. Consequently, we study a physically motivated extension of LOCC: multi-state LOCC. Here, one considers simultaneous LOCC transformations of finitely many pure states. In the multipartite case, we show one can change the stochastic LOCC (SLOCC) class of the individual states; that one can perform transformations not possible in the single-copy case, transferring entanglement from one state to the other; provide examples of multipartite entanglement catalysis; and find improved probabilistic protocols. In the bipartite case, we find numerous non-trivial LU transformations.
569	**Entanglement transformations in permutation symmetric classes** *Cornelia Spee [1], Martin Hebenstreit [1], Nicky Kai Hong Li [1], Julio de Vicente [2], Barbara Kraus [1]* *[1] University of Innsbruck, [2] Universidad Carlos III de Madrid* Despite their involved structure transformations via local operations assisted by classical communication (LOCC) are an active field of research due to their relevance to entanglement theory and their natural occurrence in communication scenarios. However, generically no LOCC transformations are possible among multipartite pure states. Therefore, we focus in this work on entanglement classes containing permutation symmetric states, which are promising candidates for a richer LOCC structure and study their entanglement properties. We characterize the local symmetries of important classes and identify possible LOCC transformations, as well as states which can neither be reached via finite-round LOCC protocols nor converted to some other pure state within a single round of LOCC.
570	**State transformations within entanglement classes containing permutation-symmetric states: 3- & 4-Qutrit Cases** *Nicky Kai Hong Li [1], Martin Hebenstreit [1], Barbara Kraus [1], Cornelia Spee [1], Julio de Vicente [2]* *[1] University of Innsbruck, [2] Universidad Carlos III de Madrid* Permutation-symmetric states are both mathematically interesting and physically relevant. To understand these states better, it is important to study their entanglement properties and the allowed transformations via local operations assisted by classical communication (LOCC) which are the free operators in the resource theory of entanglement. We characterize the stabilizers of a large class of pure multipartite permutation-symmetric states and study state transformations restricted to finite-round LOCC within stochastic LOCC (SLOCC) classes that contain these states. In this poster, we focus only on 3- and 4-qutrit permutation-symmetric pure states and present their local symmetries and interesting LOCC transformations in details.

571 Party-local Clifford transformations of graph states

Tristan Kraft, Matthias Englbrecht, Barbara Kraus, University of Innsbruck

We consider graph states under party-local Clifford transformations (PLC). Such transformations arise e.g. in quantum networks where shared entanglement between spatially close nodes complements local operations. Bravyi et al solved PLC equivalence of graph states for 3 parties via the introduction of an entanglement generating set (EGS), a finite set of states into a collection of which every graph state decomposes uniquely under PLC. We show that EGS is infinite for ≥ 3 parties and that finding states in the EGS is equivalent to the classification of tuples of alternating matrices. Moreover, we generalize the notion of local complementation, which describes the action of local Clifford transformations on graph states.

572 Reassessing the computational advantage of quantum-controlled ordering of gates

Martin Johannes Renner, Časlav Brukner, Universität Wien

In quantum computation, indefinite causal structures allow to perform certain tasks more efficiently than any conventional (causal) quantum algorithm. For example, the quantum switch can decide whether two unitary gates commute or anticommute with a single call to each gate, while in any causal quantum algorithm at least one gate has to be called twice. A generalization of this task to n unitary gates, can be solved with the quantum-n-switch and a single call to each gate, while it was expected that the best causal algorithm calls $O(n^2)$ gates. We present more efficient causal algorithms for this task and conclude that this advantage is smaller than expected so far.

573 Global vs local bath in superconducting waveguide QED experiments

Aleksei Sharafiev, Mathieu Juan, Gerhard Kirchmair, Institut for Quantum Optics and Quantum information

Characterizing and controlling the coupling between qubits and environmental degrees of freedom is one of the central problems in quantum systems engineering. The coupling of one quantum system to multiple environmental degrees of freedom attracted significant attention during the last years both on theoretical and experimental sides, especially in the field of superconducting quantum circuits. In this work we investigate the problem in the context of 3D waveguide Quantum Electrodynamics (wQED), and demonstrate that in a typical experimental situation the environment can be considered as consisting of a global and a local bath. We realize an experimental protocol to extract the respective temperatures of the two baths.

574 Fluorescence detection of the position and variance operators.

Giovanni Cerchiari, Lorenzo Dania, Yannick Weiser, Dmitry S. Bykov, Tracy Northup, Rainer Blatt
University of Innsbruck

We develop an optical technique to perform the quantum state tomography of a dipolar scatterer's state of motion. We approach this problem by experimenting with trapped ions and trapped silica nanoparticle as levitated dipolar scatterers. By manipulating the light emitted by the scatterers, we aim to measure the position and the variance operators of the scatterer's state of motion. This will allow us to identify quantum states of motion such as superposition of Fock states, squeezed states or cat states, in a full-optical manner.

575 Towards quantum simulations with two-dimensional ion crystals

Matthias Bock [1], Helene Hainzer [1], Dominik Kiesenhofer [1], Tuomas Ollikainen [1], Philip Holz [2], Christian Roos [1,2]
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Trapped ions are a well-established platform for analog or variational quantum simulation of quantum magnetism. Up to now, ions in linear Paul traps allow for simulations of the 1D Ising model with up to 50 spins. In our project, we aim for extending this approach to the second dimension which will enable studies of 2D non-equilibrium physics with a larger particle number (> 50). Here we present the first results from our new ion trap apparatus whose centerpiece is a novel monolithic micro-fabricated linear Paul trap, enabling us to create the anisotropic potentials required for trapping 2D ion crystals with simultaneous optical access for imaging and single-ion addressing.