Abstracts: Posters
33rd SFB FoQuS meeting, University of Innsbruck, 14-15 July 2016

Christoph Dittel, Universität Innsbruck
Many-body quantum interference on hypercubes

Beyond the regime of distinguishable particles, many-body quantum interferences in influence quantum walks in an intricate manner. However, symmetries of the single-particle transformation matrix alleviate this complexity and even allow the analytic formulation of suppression laws, which predict final states to occur with a vanishing probability due to total destructive interference. Here we investigate the symmetries of hypercube graphs and their generalizations with arbitrary identical subgraphs on all vertices. We find that initial many-particle states, which are invariant under self-inverse symmetries of the hypercube, lead to a large quantity of suppressed final states. The condition for suppression is determined solely by the initial symmetry, while the fraction of suppressed states is given by the number of independent symmetries of the initial state. Our findings reveal new insights in particle statistics for ensembles of indistinguishable bosons and fermions and may represent a first step towards many-particle quantum protocols in higher-dimensional structures.

Nicolai Friis, Universität Innsbruck
Thermodynamics and energetics of creating correlations

A fundamental connection between thermodynamics and information theory arises from the fact that correlations exhibit an inherent work value. Conversely, energy is needed to create correlations. Here, we present investigations into this question for both non-interacting systems, and for systems where interactions cannot be controlled or removed. We present ultimate bounds and optimal protocols for the non-interacting case, and discuss general strategies outperforming those bounds for naturally coupled systems. Our results are illustrated for some examples of interest.

Alexander Glätzle, IQOQI Innsbruck
Adiabatic Quantum Computing with Rydberg Atoms

Based on adiabatic quantum computing and the parity architecture we propose a quantum annealer implementation with cold atoms laser excited to Rydberg states in optical lattices. As a particular example we consider Restricted Boltzmann machines (RBM) which recently regained considerable interest as building blocks for quantum deep machine learning applications using adiabatic quantum computing protocols. In the parity architecture, the required bipartite graph for the RBM reduces to a simple square lattice with rectangular shape and the interactions are local 4-body constraints. As a key ingredient of our set-up we introduce extra auxiliary qubit atoms on each plaquette to effectively engineer the 4-body interactions in the odd parity sector using mixtures of Rydberg dressed Rubidium and cesium atoms.

Philipp Hauke, Universität Innsbruck
Measuring multipartite entanglement via dynamic susceptibilities

Entanglement plays a central role in our understanding of quantum many body physics, and is fundamental in characterizing quantum phases and quantum phase transitions. Developing protocols to detect and quantify entanglement of many-particle quantum states is thus a key challenge for present experiments. Here, we show that the quantum Fisher information, representing a witness for genuinely multipartite entanglement, becomes measurable for thermal ensembles via the dynamic susceptibility, i.e., with resources readily available in present cold atomic gas and condensed-matter experiments. This moreover establishes a fundamental connection between multipartite entanglement and many-body correlations contained in response functions, with direct implications close to quantum phase transitions. There, the quantum Fisher information becomes universal, allowing us to identify strongly entangled phase transitions with a divergent multipartiteness of entanglement. We illustrate our framework using paradigmatic quantum Ising models, and point out potential signatures in optical-lattice experiments.

Martin Hebenstreit, Universität Innsbruck
Performance of compressed quantum computation

It has been shown that the Ising interaction of a 1D-chain consisting out of n qubits can be simulated using a log(n) qubit universal quantum computer making use of compression of match gate circuits [B. Kraus, Phys. Rev. Lett. 107, 250503 (2011)]. Such a simulation has been performed on a five qubit nuclear magnetic resonance quantum simulator, simulating a 32 qubits chain, recently [Z. Li, H. Zhou, C. Ju, H. Chen, W. Zheng, D. Lu, X. Rong, C. Duan, X. Peng, and J. Du, Phys. Rev. Lett. 112, 220501 (2014)]. In order to test the performance of the recently available few qubit quantum computer (IBM) we perform the simulation of the compressed circuit on it and compare the results to the ones obtained using the NMR quantum computer.

Georgy Kazakov, TU Wien
Active optical standards with trapped atoms and ions: approaches and difficulties

Bad cavity laser is a laser where the linewidth of the cavity mode is broader than the gain profile. Frequency of radiation emitted by such laser is robust with respect to fluctuations of the cavity length. It opens the possibility to create a highly stable active optical frequency standard. Theoretical estimations shows that such bad-cavity lasers may have millihertz-narrow linewidth. Being combined with high-precision passive optical clocks in the manner similar to combination of hydrogen masers and Cs beam clocks in national metrology institutions, these lasers may constitute an ultra-high performance frequency reference.

Creation of such a bad-cavity laser faces a number of challenges related to collisions, escape of the atoms out of the trapping potential, necessity of pumping, etc. Also the lasers may operate in unstable regimes, where the amplitude of the output radiation demonstrate complex temporal pattern. We discuss different approaches towards the construction of the bad cavity active optical frequency standards. Also, we present an efficient method for analysis of stability of lasers with inhomogeneously broadened gain, and investigate steady-state solutions and their stability for bad cavity lasers with spin-1/2 atoms.

Kirill Lakhmanskiy, Universität Innsbruck
High temperature superconducting surface ion traps

Ion traps are a promising tool for quantum simulators and quantum computers [1]. Microfabricated surface traps offer the possibility to miniaturize ion traps, which is a possible route towards a scalable quantum computer. However, the proximity of the ions to the surface of the trap leads to motional heating, the origin of which is not well understood [2].

To investigate different sources of motional heating, we operate a surface ion trap made of YBCO, a high-temperature superconducting material. The trap is designed in such a way that Johnson noise should be the dominant source of motional heating above the critical temperature Tc ~85 K, whereas below Tc it should be negligible compared to other noise sources. Using a local heating element, we adjust the temperature of the trap chip and observe the superconducting transition by measuring the Q factor of the RF resonant circuit or the resistance of on-chip structures. Probing the motional heating of a trapped ion, we expect to observe pronounced changes in the characteristics of the electric field noise in a small temperature range around Tc.

[1] R. Blatt, C.F. Roos, Nature Phys. 8, 277 (2012)
[2] M. Brownnutt, M. Kumph, P. Rabl, and R. Blatt, arXiv:1409.6572 (2014)

Esteban Martinez, Universität Innsbruck
Real-time dynamics of gauge field theories with a few-qubit quantum computer

Gauge theories are fundamental to our understanding of interactions between the elementary constituents of matter as mediated by gauge bosons. However, computing the real-time dynamics in gauge theories is a notorious challenge for classical computational methods. This has recently stimulated theoretical effort, using Feynman's idea of a quantum simulator, to devise schemes for simulating such theories on engineered quantum-mechanical devices, with the difficulty that gauge invariance and the associated local conservation laws (Gauss laws) need to be implemented. Here we report the experimental demonstration of a digital quantum simulation of a lattice gauge theory, by realizing (1 + 1)-dimensional quantum electrodynamics (the Schwinger model) on a few-qubit trapped-ion quantum computer. We are interested in the real-time evolution of the Schwinger mechanism, describing the instability of the bare vacuum due to quantum fluctuations, which manifests itself in the spontaneous creation of electron–positron pairs. To make efficient use of our quantum resources, we map the original problem to a spin model by eliminating the gauge fields in favor of exotic long-range interactions, which can be directly and efficiently implemented on an ion trap architecture. We explore the Schwinger mechanism of particle–antiparticle generation by monitoring the mass production and the vacuum persistence amplitude. Moreover, we track the real-time evolution of entanglement in the system, which illustrates how particle creation and entanglement generation are directly related.
Our work represents a first step towards quantum simulation of high-energy theories using atomic physics experiments — the long-term intention is to extend this approach to real-time quantum simulations of non-Abelian lattice gauge theories.

Hernán Pino, IQOQI Innsbruck
Quantum interference of a microsphere

We propose and analyze an all-magnetic scheme to perform a Young's double slit experiment with a micron-sized superconducting sphere of mass & 1013 amu. We show that its center of mass could be prepared in a spatial quantum superposition state with an extent of the order of half a micrometer. The scheme is based on magnetically levitating the sphere above a superconducting chip and letting it skate through a static magnetic potential landscape where it interacts for short intervals with quantum circuits. In this way a protocol for fast quantum interferometry is passively implemented. Such a table-top earth-based quantum experiment would operate in a parameter regime where gravitational energy scales become relevant. In particular, we show that the faint parameter-free gravitationally-induced decoherence collapse model, proposed by Diósi and Penrose, could be unambiguously falsified.

Katja Ried, Universität Innsbruck
Quantum theory meets causal models

The framework of causal models, originally developed in the context of classical statistics and machine learning, provides powerful conceptual and mathematical tools for understanding causality. The process of adapting this framework to accommodate quantum mechanics yields both fundamental insights and practical applications, some of which I will present in this poster.

David Sauerwein, Universität Innsbruck
Source and accessible entanglement of few-body systems

Entanglement is the resource to overcome the natural limitations of spatially separated parties restricted to local operations assisted by classical communication (LOCC). Recently, two new classes of operational entanglement measures, the source and the accessible entanglement, for arbitrary multipartite states have been introduced. Whereas the source entanglement measures from how many states the state of interest can be obtained via LOCC, the accessible entanglement measures how many states can be reached via LOCC from the state at hand. We consider here pure bipartite as well as multipartite states and derive explicit formulas for the source entanglement. Moreover, we obtain explicit formulas for a whole class of source entanglement measures that characterize the simplicity of generating a given bipartite pure state via LOCC. Furthermore, we show how the accessible entanglement can be computed numerically. For generic four-qubit states we first derive the necessary and sufficient conditions for the existence of LOCC transformations among these states and then derive explicit formulas for their accessible and source entanglement.

Katharina Schwaiger, Universität Innsbruck
Operational multipartite entanglement measures

We introduce two operational entanglement measures that are applicable for arbitrary multipartite (pure or mixed) states. One of them characterizes the potentiality of a state to generate other states via local operations assisted by classical communication and the other characterizes the simplicity of generating the state at hand. We show how these measures can be generalized to two classes of entanglement measures. Moreover, we compute the new measures for pure few-partite systems and use them to characterize the entanglement contained in a three-qubit state. We identify the Greenberger-Horne-Zeilinger and W state as the most powerful pure three-qubit states regarding state manipulation.

RuGway Wu, TU Wien

<u>Towards studies of quantum back-action, cooling and thermalization of 1D Bose gas by output coupling</u>

Output coupling atoms and detecting them in time of flight will allow minimum invasive measurements on trapped ultracold gases [1], as well as studying the effect of dissipation. In particular, we plan to apply this technique to study quantum gases trapped in a double-well on the atom chip [2]. We will investigate the realization of a relative phase between two initially independent BECs through measurement [3,4], and characterize measurement back-action of a coherently split BEC [5,6]. With continuous, uniform output coupling, we will study the cooling of one-dimensional Bose gas through the phenomenon modeled by quantum potter's wheel [7,8]. We will pursue the previously unobserved vacuum fluctuations, leading to reduced cooling efficiency. [1] R. Bücker et al., New J. Phys. 11, 103039 (2009) [2] S. Hofferberth et al., Nature Phys. 2, 710 (2006) [3] J. Javanainen & S. M. Yoo, Phys. Rev. Lett 76, 161 (1996). [4] Y. Castin & J. Dalibard, Phys. Rev. A 55, 4330 (1997). [5] M. Lewenstein & L. You, Phys. Rev. Lett. 77, 3489 (1996). [6] J. Javanainen & M. Wilkens, Phys. Rev. Lett. 78, 4675 (1997). [7] B. Rauer et al., Phys. Rev. Lett. 116, 030402 (2016). [8] P. Grisins et al., Phys. Rev. A, 93, 033634 (2016).