Q 20: Quantum Information: Concepts and Methods 3

Time: Tuesday 10:30–13:00 Location: SCH A118

Q 20.1 Tue 10:30 SCH A118

Experimental investigation of the uncertainty principle using entangled photons — •Robert Prevedel[1], Deny Hamel[1], Roger Colbeck[2], Kent Fisher[1], and Kevin Resch[1] — [1]Institute for Quantum Computing, University of Waterloo, Waterloo, N2L 3G1, ON, Canada — [2]Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Waterloo, Ontario N2L 2Y5, Canada

The uncertainty principle, first formulated by Heisenberg provides a fundamental limitation on an observer's ability to simultaneously predict the outcome when one of two measurements is performed on a quantum system. However, if the observer has access to a particle which is entangled with the system, his uncertainty is generally reduced: indeed, if the particle and system are maximally entangled, the observer can predict the outcome of both measurements precisely. This effect has recently been quantified by Berta et al. in a new, more general uncertainty relation. Here we perform experiments to probe the validity of this new inequality using entangled photon pairs. The behavior we find agrees with the predictions of quantum theory, satisfying the new uncertainty relation. An optical delay line that serves as a quantum memory, in combination with fast feed-forward allows an observer to gain more information and hence lower uncertainty about the outcome of an measurement than would be possible without the entanglement. This shows not only that the reduction in uncertainty caused by entanglement can be significant in practice, but also demonstrates the use of the inequality to witness entanglement.

Q 20.2 Tue 10:45 SCH A118

Reconstructing CV-Quantum Optical States by Compressed Sensing — •Vincent Nesme[1], Matthias Ohliger[1], David Gross[2], and Jens Eisert[1] — [1]Universität Potsdam, Institut für Physik und Astronomie (Haus 28) Karl-Liebknecht-Strasse 24/25 14476 Potsdam, Germany — [2]ETH Zürich, Theoretische Physik, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland

The reconstruction of quantum states from measurement results is a challenging task both on the experimentalist and on the post-processing side. In recent work, compressed sensing has been used to reduce the number of measurements needed to reconstruct a state with rank r in a n-dimensional Hilbert space from $O(n^2)$ to $O(rn \log n)$ where the post-processing can be done efficiently with the help of semidefinite programming. We extend this result to tackle the reconstruction of a continuous-variable (CV) state of a quantum optical system. We discuss the recovery of the Wigner function both from homodyne-measurement and photon-counting and also address the question of resistance to noise.

Q 20.3 Tue 11:00 SCH A118

Taming multiparticle entanglement — •Bastian Jungnitsch[1], Tobias Moroder[1], and Otfried Gühne[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, A-6020 Innsbruck, Austria — [2]Fachbereich Physik, Universität Siegen, Walter-Flex-Straße 3, D-57068 Siegen, Germany

Current experiments have succeeded in manipulating up to fourteen qubits [1], moving tasks like measurement-based quantum computation closer to the realm of possibility.

We present an approach to characterize genuine multiparticle entanglement using appropriate approximations in the space of quantum states [2]. This leads to a criterion for entanglement which can easily be calculated using semidefinite programming and improves all existing approaches significantly. Experimentally, it can also be evaluated when only some observables are measured. Furthermore, it results in a computable entanglement monotone for genuine multiparticle entanglement which reduces to the negativity in the bipartite case.

Based on this criterion, we develop an analytical approach for the entanglement detection in graph states. When specialized to, e.g., linear cluster states, this approach leads to witnesses whose white noise robustnesses approach unity exponentially fast with an increasing number of qubits.

[1] T. Monz et al., arXiv:1009.6126
[2] B. Jungnitsch, T. Moroder and O. Gühne, arXiv: 1010.6049

Q 20.4 Tue 11:15 SCH A118

Measuring entanglement in condensed matter systems — •Marcus Cramer[1], Martin Plenio[1,2], and Harald Wunderlich[1] — [1]Institut für Theoretische Physik, Universität Ulm, Germany — [2]QUOLS, Imperial College London, UK

We show how entanglement may be quantified in spin and cold atom many-body systems using standard experimental techniques only. The scheme requires no assumptions on the state in the laboratory and a lower bound to the entanglement can be read off directly from the scattering cross section of Neutrons deflected from solid state samples or the time-of-flight distribution of cold atoms in optical lattices, respectively. This removes a major obstacle which so far has prevented the direct and quantitative experimental study of genuine quantum correlations in many-body systems: The need for a full characterisation of the state to quantify the entanglement contained in it. Instead, the scheme presented here relies solely on global measurements that are routinely performed and is versatile enough to accommodate systems and measurements different from the ones we exemplify in this work.

Q 20.5 Tue 11:30 SCH A118

Entanglement detection in systems of spin-j particles with collective observables — •Giuseppe Vitagliano[1] and Géza Tóth[1,2,3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary

We discuss the problem of finding inequalities useful to detect entanglement in systems of particles with a spin higher than 1/2. We focus on uncertainty relations based on the knowledge of the first two moments of global observables, such as for example the total spin components. We compare the various inequalities obtained from the point of view of their usefulness to detect entanglement by characterizing the experimental effort needed and by studying the states that violate them.

Q 20.6 Tue 11:45 SCH A118

Volume law scaling of entanglement entropy in spin-1/2 chains. — •Giuseppe Vitagliano[1], Arnau Riera[2], and José Ignacio Latorre[3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]Institute of Physics and Astronomy, University of Potsdam, D-14476 Potsdam, Germany — [3]Department d' Estructura i Constituents de la Matéria, Universitat de Barcelona, E-08028 Barcelona, Spain

We address the question whether a Hamiltonian with only nearest neighbor interaction can have a highly entangled ground state, in the sense that it presents a volume law scaling of the block entanglement entropy. For typical quantum systems the block entanglement entropy of the ground state follows an area-law scaling, with a logarithmic violation for quantum critical models. Nevertheless, we explicitly construct a spin-1/2 chain Hamiltonian that has the expected properties, breaking the translational invariance of the model. Its ground state is characterized by an accumulation of singlet bonds across the half chain.This result is also related to the QMA completeness of the 1D local Hamiltonian problem.

Q 20.7 Tue 12:00 SCH A118

Robust and Fragile Entanglement in Qubit Environments — •Jaroslav Novotny[1,2], Gernot Alber[1], and Igor Jex[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE CTU in Prague, Czech Republic

The asymptotic decoherence originating from iteratively applied random unitary couplings between distinguishable qubits of a quantum network is investigated. Within this framework the resulting asymptotic dynamics of a subsystem and its residual qubit environment is explored without any further simplifying assumptions concerning the coupling strength or the number of relevant couplings between subsystem and its environment or the numbers of qubits involved. The dependence of the resulting asymptotic decoherence and entanglement decay of the subsystem on the interaction topology and on the size and initial state of the environment is discussed. It is shown that there are two classes of entangled states whose asymptotic entanglement decay depends on the size of the surrounding qubit environment in a characteristic and completely different way. The asymptotic entanglement of

members of the first class is destroyed already for a finite and usually very small number of environmental qubits. Besides this class of fragile entangled states there is also the second class of robustly entangled states whose entanglement is not destroyed completely for any finite size of the surrounding qubit environment. A simple analytical criterion is presented which is capable of distinguishing between these two classes in the case of two-qubit states.

Q 20.8 Tue 12:15 SCH A118

Permutationally Invariant Quantum Tomography — •Géza Tóth[1,2,3], Witlef Wieczorek[4,5], David Gross[6], Roland Krischek[4,5], Christian Schwemmer[4,5], and Harald Weinfurter[4,5] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary — [4]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany — [5]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80799 Garching, Germany — [6]Institute for Theoretical Physics, Leibniz University Hannover, D-30167 Hannover, Germany

We present a scalable method for the tomography of large multi-qubit quantum registers. It acquires information about the permutationally invariant part of the density operator, which is a good approximation to the true state in many, relevant cases. Our method gives the best measurement strategy to minimize the experimental effort as well as to minimize the uncertainties of the reconstructed density matrix. We calculate the measurements needed for up to 14 qubits, and also compute the required total count, i.e., how many times the experiments have to be repeated for obtaining sufficiently low uncertainties. We note that the method has been implemented for the experimental tomography of a four-qubit symmetric Dicke state [1].

[1] See the talk by C. Schwemmer et al.

Q 20.9 Tue 12:30 SCH A118

Permutationally invariant tomography of a four qubit symmetric Dicke state — •Christian Schwemmer[1,2], Géza Tóth[3,4,5], Witlef Wieczorek[6], David Gross[7], Roland Krischek[1,2], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, D-85748 Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80797 München — [3]Department of Theoretical Physics, The University of the Basque Country, E-48080 Bilbao — [4]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao — [5]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, H-1525 Budapest — [6]Faculty of Physics, University of Vienna, A-1090 Vienna — [7]Institute for Theoretical Physics, Leibniz University Hannover, D-30167 Hannover

Multi-partite entangled quantum states play an important role for many quantum information tasks. Therefore, efficient measurement schemes for characterizing these states are needed. As shown by Tóth et al. [1], when restricting to permutationally invariant states the measurement effort scales only quadratically with the number of qubits. Here, we present experimental results of the tomographic analysis of a photonic four qubit Dicke state. Instead of 81 basis settings for full tomography only 15 basis settings have to be measured. We investigate the possibility of permutationally invariant tomography for photonic systems with a larger number of qubits on the example of a six photon symmetric Dicke state. Due to the low count rates for such systems, full tomography is practically impossible.

[1] Tóth et al., Phys. Rev. Lett., in press; talk by Tóth

Q 20.10 Tue 12:45 SCH A118

Simulation of relativistic effects with ultracold atoms in bichromatic optical lattices — •Christopher Grossert, Tobias Salger, Sebastian Kling, and Martin Weitz — Institut für Angewandte Physik, Wegelerstr.8 , 53115 Bonn, Germany

We propose a scheme to simulate relativistic effects with ultracold rubidium atoms in bichromatic optical lattice potentials. In an earlier experiment, we have investigated the energy splitting betweeen the first and second excited Bloch band of a Fourier- synthesized lattice potential created by superimposing two lattice harmonics with different spatial periodicities [1]. Interestingly for specific values of the potential depths of the lattice harmonics, the energy dispersion for ultracold atoms shows a linear behaviour, where the dynamics of the particles can be described by the linear Dirac equation. We expect to observe relativistic effects like Klein tunneling, where ultrarelativistic particles penetrate a potential barrier without significant damping, regardless of the height and length of the barrier [2]. This effect has already been demonstrated in graphene, which shows a similar relativistic energy dispersion for free electrons [3]. More- over, we expect to be able to investigate effects predicted by the linear and non-linear Dirac equation.

References

[1] Salger, T. ; Geckeler, C. ; Kling, S. ; Weitz, M.: Phys. Rev. Lett. **99** 190405 (2007)
[2] Klein, O.: Z.Physik **53** 127 (1929)
[3] Stander, N. ; Huard, B. ; Goldhaber-Gordon, D.: Phys. Rev. Lett. **102** 026807 (2009)