# Q 42 Quanteninformation II

Zeit: Dienstag 14:00–16:00 Raum: HU Audimax

Q 42.1 Di 14:00 HU Audimax

**Demonstration of the Deutsch-Jozsa Algorithm with Single Photons** — •Sven Ramelow, Thomas Aichele, Matthias Scholz, and Oliver Benson — Humboldt-Universität zu Berlin, AG Nanooptik, Hausvoigteiplatz 5-7, 10117 Berlin

Among the numerous concepts of implementing qubits for quantum computation, single photons have become a particularly useful working horse for studying entanglement, quantum information and quantum computation. As one of the first quantum algorithms illustrating the vast potential of quantum computation, the Deutsch-Jozsa Algorithm has already been realized in NMR[1] or ion-trap quantum computing[2].

The Deutsch-Jozsa Algorithm evaluates if a function is constant or balanced. In the case of a 2-bit function, the algorithm can be demonstrated using single photons and linear optics[3]. In our experiment, the first qubit is implemented by two spatial modes of the photon and the second qubit by the polarization of the photon. Single photons are produced by a source using InP quantum dots[4]. Further experimental demonstrations of fundamental quantum effects will be discussed.

[1] N. Linden, H. Barjat, R. Freeman, Chem. Phys. Lett. 296, 61,(1998)
[2] S. Gulde, M. Riebe, G. Lancaster, C. Becher, J. Eschner, H. Häffner, F. Schmidt-Kaler, I. Chuang, R. Blatt, Nature 421, 48, (2003)
[3] S. Tekeuchi, Phys. Rev. A 62, 032301 (2000)
[4] V.Zwiller, T. Aichele, W. Seifert, J. Persson, O. Benson, APL 82, 1509, (2003)

Q 42.2 Di 14:15 HU Audimax

**Bell inequalities for graph states** — •Otfried Gühne[1], Geza Toth[2], Philipp Hyllus[3], and Hans J. Briegel[1,4] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, A-6020 Innsbruck — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching — [3]Institut für Theoretische Physik, Universität Hannover, Appelstraße 2, D-30167 Hannover — [4]Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 25, A-6020 Innsbruck

In the last years graph states have attracted an increasing interest in the field of quantum information theory. Graph states form a family of multi-qubit states which comprises many popular states such as the GHZ states and the cluster states. They also play an important role in applications. For instance, measurement based quantum computation uses graph states as resources. From a theoretical point of view, it is remarkable that graph states allow for a simple description in terms of stabilizing operators.

In this contribution, we investigate the non-local properties of graph states. We derive a family of Bell inequalities which require three measurement settings for each party and are maximally violated by graph states. In turn, any graph state violates at least one of the inequalities. We show that for certain types of graph states the violation of these inequalities increases exponentially with the number of qubits. We also discuss connections to other entanglement properties such as the positivity of the partial transpose or the geometric measure of entanglement.

Q 42.3 Di 14:30 HU Audimax

**Tough error models** — •Michael Reimpell and Reinhard F. Werner — Institut für Mathematische Physik, TU Braunschweig, Mendelssohnstraße 3, 38106 Braunschweig

We study the ability to correct a noisy quantum channel, given only the number of independent Kraus operators of the channel. Consider a noisy channel on a d-dimensional system, which requires e Kraus operators, or error syndromes. If e is sufficiently small, one can find a Knill-Laflamme error correcting code, by which a system of fairly large dimension c can be transmitted through the channel. We consider the conditions on (c,d,e) making such correction possible without further information on the error operators. A tough error model is a set of error syndromes which cannot be corrected perfectly and has the additional property that any subset can be corrected, already on the grounds of the size of e. We present analytic and numerical results on the triples (c,d,e) allowing correction, as well as on tough error models.

Q 42.4 Di 14:45 HU Audimax

**Quantum estimation of higher dimensional systems** — •Thorsten Bschorr and Matthias Freyberger — Abteilung Quantenphysik, Universität Ulm, 89069 Ulm

We present the estimation of quantum states of higher dimensional systems. This includes the estimation of entangled subsystems. Such an estimation process consists of consecutive measurements on a finite ensemble. From the measured frequencies one can infer the quantum states using suitable estimators. We explore the application of these ideas to higher dimensions. We show how the problem of exponentially growing parameter spaces can be treated using Quasi Monte–Carlo methods [1]. In addition we discuss the use of uniformly distributed measurement bases in the Hilbert space using the Fubini–Study metric.

[1] H. Niederreiter, *Random number generation and Quasi-Monte Carlo methods*, (Society for Industrial and Applied Mathematics, Philadelphia, 1992).

Q 42.5 Di 15:00 HU Audimax

**Localizable Entanglement** — •Markus Popp[1], Frank Verstraete[1], Ignacio Cirac[1], and Miguel-Angel Martín-Delgado[2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Departamento de Física Teórica I, Universidad Complutense de Madrid, E-28040, Spain

We consider systems of interacting spins and study the entanglement that can be *localized*, on average, between two separated spins by performing local measurements on the remaining spins. This concept of *Localizable Entanglement* (LE) [1] leads naturally to notions like entanglement length and entanglement fluctuations. For both spin-1/2 and spin-1 systems we prove that the LE of a pure quantum state can be lower bounded by classical correlation functions. We further propose a scheme, based on matrix-product states and the Monte Carlo method, to efficiently calculate the LE for quantum states of a large number of spins. The virtues of LE are illustrated for various spin models. In particular, characteristic features of a quantum phase transition such as a diverging entanglement length can be observed. We also give examples for pure quantum states exhibiting a diverging entanglement length but finite correlation length [2]. We have numerical evidence that the ground state of the antiferromagnetic spin-1 Heisenberg chain can serve as a perfect quantum channel. Furthermore we apply the numerical method to mixed states and study the entanglement as a function of temperature.

References: [1] F. Verstraete, M. Popp, and J.I. Cirac, Phys. Rev. Lett. **92**, 027901 (2004). [2] F. Verstraete, M.A. Martin-Delgado, and J.I. Cirac, Phys. Rev. Lett. **92**, 087201 (2004).

Q 42.6 Di 15:15 HU Audimax

**Entanglement Witnesses in Spin Models** — •Geza Toth — Theoretical Division, Max Planck Institute for Quantum Optics, Hans Kopfermann Str. 1, D 85748 Garching, Germany

Entanglement witnesses have recently raised a lot of attention as powerful tools for detecting quantum entanglement. They are usually multi-qubit operators which must be decomposed into a sum of local operators for measurement.

In our presentation we follow a different route. We construct entanglement witnesses using fundamental quantum operators of spin models which are easy to measure. By choosing the Hamiltonian as such an operator, our method can be used for detecting entanglement by energy measurement. We apply this method to the Heisenberg model in a cubic lattice with a magnetic field, the XY model and other familiar spin systems.

Our method can efficiently be used for entanglement detection in spin systems in thermal equilibrium. It is of experimental interest that for many familiar spin lattices energy can be measured indirectly through correlation measurements. For further details please see quant-ph/0406061.

Q 42.7 Di 15:30 HU Audimax

**Bi-partite and global entanglement in a many-particle system with collective spin coupling** — •Cristian Ionescu[1,2], Razmik Unanyan[1,3], and Michael Fleischhauer[1] — [1]Fachbereich Physik, Technische Universität Kaiserslautern — [2]Institute for Space Science, Bucharest, Romania — [3]Institute for Physical Research of Armenian National Academy of Sciences, Ashtarak, Armenia

Bipartite and global entanglement are analyzed for the ground state of a system of $N$ spin 1/2 particles interacting via a collective spin-spin coupling described by the Lipkin-Meshkov-Glick (LMG) Hamiltonian. Under certain conditions which includes the special case of a supersymmetry, the ground state can be constructed analytically.

In the case of an antiferromagnetic coupling and for an even number of particles this state undergoes a smooth crossover as a function of the continuous anisotropy parameter $\gamma$ from a separable ($\gamma = \infty$) to a maximally entangled many-particle state ($\gamma = 0$). From the analytic expression for the ground state bipartite and global entanglement are calculated. In the thermodynamic limit a discontinuous change of the scaling behavior of the bipartite entanglement is found at the isotropy point $\gamma = 0$. For finite systems with total spin $J = N/2$ the scaling behavior changes at $\gamma_{\rm crit} = 1/J$.

Q 42.8 Di 15:45 HU Audimax

**Detecting entanglement with the stabilizer formalism** — •Geza Toth[1] and Otfried Gühne[2] — [1]Theoretical Division, Max Planck Institute for Quantum Optics, Hans Kopfermann Str. 1, D 85748 Garching, Germany — [2]Institut für Quantenoptik und Quanteninformation,Österreichische Akademie der Wissenschaften,Innsbruck A-6020, Austria

Stabilizer theory plays a central role in error correction and fault tolerant quantum computation. We investigate how it can be used for constructing sufficient conditions for entanglement. All our criteria detect states close to Greenberger-Horne-Zeilinger (GHZ) states, cluster and graph states. GHZ states have intensively been studied as maximally entangled states. Cluster and graph states raised a lot of interest, since they allow for measurement based quantum computing. They naturally arise in spin chains, and their entanglement is more immune to noise than that of the GHZ state.

In this talk we will derive entanglement conditions using the stabilizer theory. These conditions will be presented in the form of entanglement witness operators. It is important from the experimental point of view that our constructions are robust against noise and they make it possible for detecting multi-qubit entanglement with the minimal two local measurement settings.

Beside entanglement witnesses, nonlinear entanglement conditions will also be constructed using the stabilizer theory. We also discuss interesting connections between the witnesses and some Bell inequalities. For further details, please see quant-ph/0405165.