Q 8: Quanteninformation: Konzepte und Methoden 2

Time: Monday 14:00–16:00 Location: V38.04

Q 8.1 Mon 14:00 V38.04

Calibration robust entanglement detection beyond Bell inequalities — Tobias Moroder[1] and •Oleg Gittsovich[2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21A, A-6020 Innsbruck, Austria — [2]Department of Physics and Astronomy, Institute for Quantum Computing, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada

In its vast majority entanglement verification is examined either in the complete characterized or totally device independent scenario. The assumptions imposed by these extreme cases are often either too weak or strong for real experiments. Here we investigate this detection task for the intermediate regime where partial knowledge of the measured observables is known, considering cases like orthogonal, sharp or only dimension bounded measurements. We show that for all these assumptions it is not necessary to violate a corresponding Bell inequality in order to detect entanglement. We derive strong detection criteria that can be directly evaluated for experimental data and which are robust against large classes of calibration errors. The conditions are even capable of detecting bound entanglement under the sole assumption of dimension bounded measurements.

Q 8.2 Mon 14:15 V38.04

Detecting entanglement in spatial interference — Clemens Gneiting[1] and •Klaus Hornberger[2] — [1]Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Universität Duisburg-Essen, Lotharstr. 1-21, 47057 Duisburg

We discuss an experimentally amenable class of two-particle states of motion giving rise to nonlocal spatial interference under position measurements. Using the concept of modular variables, we derive a separability criterion which is violated by these non-Gaussian states. While we focus on the free motion of material particles, the presented results are valid for any pair of canonically conjugate continuous variable observables and should apply to a variety of bipartite interference phenomena.

Q 8.3 Mon 14:30 V38.04

Statistical tests for quantum state reconstruction I: Theory — •Matthias Kleinmann[1], Tobias Moroder[1,2], Thomas Monz[3], Philipp Schindler[3], Otfried Gühne[1], and Rainer Blatt[2,3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck — [3]Institut für Experimentalphysik, Universität Innsbruck

In quantum state tomography and similar schemes, the measured data is usually not used directly but rather becomes subject of a sophisticated reconstruction procedure that squeezes the data into a quantum state. In general such techniques are only admissible if the statistical error - as due to low sampling - dominates over the systematical errors, such as misaligned measurement bases. We here present tests that allow to detect situations in which a state reconstruction will become statistically inadmissible. In particular, the positivity of the density operator and the linear dependencies that occur in overcomplete tomography lead to strong conditions on the measured data. Furthermore, we argue, that certain unphysical properties of naive reconstruction schemes are merely statistical effects and hence can be safely ignored in many situations.

Q 8.4 Mon 14:45 V38.04

Statistical tests for quantum state reconstruction II: Experiment — •Philipp Schindler[1], Thomas Monz[1], Matthias Kleinmann[2], Tobias Moroder[3], Otfried Gühne[2], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck

Quantum state tomography is nowadays routinely used in many experiments, for instance to characterize entangled quantum states or to determine input and output states of a quantum processor. Tomography reconstruction algorithms are designed to restrict the results onto physical states. These methods will always return a valid quantum state for any data and therefore it seems necessary to test the recorded data prior to reconstructing the quantum state. We directly apply statistical tests on our experimental data taken in an ion trap quantum computer. In particular, we analyze the sensitivity of these tests to various experimental imperfections like crosstalk and rotated bases.

Q 8.5 Mon 15:00 V38.04

Symmetry-adapted visualization of multi-qubit systems — •Ariane Garon, Steffen J. Glaser, and Robert Zeier — Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany

The evolution of a multi-qubit system is generally understood by analyzing the time variation of its density matrix which is given in some fixed, but arbitrary basis. As the number of entries of a density matrix grow exponentially with the number of qubits, it is usually difficult to describe the general behavior of a state during evolution. We present a symmetry-adapted method to visualize quantum states and their time evolution by considering a basis for the density matrices known as irreducible spherical tensors. The corresponding basis elements are plotted as spherical harmonics on multiple spheres relating different instances of irreducible representations of a direct product which consists of SU(2) and the symmetric group of qubit permutations. Explicit results and examples are shown for three qubits using plots on 11 spheres instead of plotting 64 matrix coefficients.

Q 8.6 Mon 15:15 V38.04

Reconstructing Density Matrices Efficiently — •Tillmann Baumgratz[1], David Gross[2], Marcus Cramer[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany — [2]Physikalisches Institut, Hermann-Herder-Straße 3, Albert-Ludwigs Universität Freiburg, D-79104 Freiburg i.Br., Germany

Recent contributions in the field of quantum state tomography for large systems have shown that the drawback of the exponential growth of the Hilbert space can be circumvented by tailored reconstruction schemes and restricting attention to certain classes of states. In this talk we discuss methods to reconstruct (mixed) density matrices that are close to matrix product operators. The reconstruction scheme only requires local information of the state – giving rise to a reconstruction scheme that scales algebraically in the system size.

Q 8.7 Mon 15:30 V38.04

Permutationally Invariant Tomography of a Six Qubit Symmetric Dicke State — •Christian Schwemmer[1,2], Géza Tóth[3,4,5], Alexander Niggebaum[1,2], Tobias Moroder[6], Philipp Hyllus[3], Otfried Gühne[6,7], and Harald Weinfurter[1,2] — [1]MPI 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]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, A-6020 Insbruck — [7]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57072 Siegen,

Multi-partite entangled quantum states are promising candidates for potential applications like quantum metrology or quantum communication. Yet, efficient tools are needed to characterize these states and to evaluate their applicability. Standard quantum state tomography suffers from an exponential increase in the measurement effort with the number of qubits. Here, we show that by restricting to permutational invariant states like GHZ, W or symmetric Dicke states the problem can be recast such that the measurement effort scales only quadratically [1]. We apply this method to experimentally analyze a six photon symmetric Dicke state generated by parametric down conversion where instead of 729 only 28 basis settings have to be measured.

[1] Tóth et al., Phys. Rev. Lett. **105**, 250403 (2010)

Q 8.8 Mon 15:45 V38.04

An algorithm for permutationally invariant state reconstruction for larger qubit numbers — •Tobias Moroder[1], Philipp Hyllus[2,3], Géza Tóth[2,3,4], Christian Schwemmer[5,6], Alexander Niggebaum[5,6], Stefanie Gaile[7], Otfried Gühne[1,8], and Harald Weinfurter[5,6] — [1]IQOQI, Innsbruck — [2]Department Theoretical Physics, Bilbao — [3]IKERBASQUE, Bilbao — [4]Research Institute for Solid State Physics and Optics, Budapest — [5]MPQ, Garching — [6]Fakultät Physik, LMU, München — [7]DTU Mathematics, Lyngby — [8]Department Physik, Siegen

Feasible tomography schemes for large particle numbers must possess, besides an appropriate data acquisition protocol, also an efficient way to reconstruct the density operator from the observed finite data set. Since this state reconstruction task typically requires the solution of a non-linear large-scale optimization problem, this becomes another major challenge in the design of scalable tomography schemes.

In this talk we present an efficient state reconstruction scheme for permutationally invariant tomography [PRL **105**, 250403]. It works for common state-of-the-art reconstruction principles, including, among others, maximum likelihood and least squares which are the preferred choices in experiments. This is achieved by greatly reducing the dimensionality of the problem employing a particular representation of permutationally invariant states known from spin-coupling and moreover by using convex optimization, which has clear advantages regarding speed, control and accuracy in comparison to commonly employed numerical routines. First prototype implementations allow state reconstruction of 20 qubits in about 20 minutes on a standard computer.