QI 15: Quantum Information: Concepts and Methods II

Time: Thursday 9:30–12:30 Location: BEY/0137

QI 15.1 Thu 9:30 BEY/0137

Quantum dynmics induced by Pauli strings — •Roberto Gargiulo[1,2] and Robert Zeier[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]University of Cologne, Institute for theoretical physics (THP), 50937 Cologne, Germany

General quantum dynamics in qubit systems are described by independently controlled Hamiltonians consisting of sums of Pauli strings (i.e. tensor products of Pauli operators). We consider the case where each independently controlled Hamiltonian is given by a single Pauli string. We provide a unified description of the resulting dynamics relying on inherent symmetries and generated Lie algebras. This allows us to describe dynamical properties in terms of simple invariants and to detail possible free-fermionic mappings. We expand and extend recent work [1-3] which enables us to re-interpret them in a general framework. Our description addresses various questions of controllability, computational power, and many-body properties, especially in the context of Heisenberg picture and operator subspaces.

[1] Chapman et al. Quantum 4, 278 (2020)
[2] Kökcü et al., arXiv:2409.19797
[3] Aguilar et al. arXiv:2408.00081

QI 15.2 Thu 9:45 BEY/0137

Robust certification of non-projective measurements — •Raphael Brinster[1], Peter Tirler[2], Shishir Khandelwal[3], Michael Meth[2], Hermann Kampermann[1], Dagmar Bruss[1], Rainer Blatt[2,4], Martin Ringbauer[2], Armin Tavakoli[3], and Nikolai Wyderka[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf — [2]Institut für Experimentalphysik, Universität Innsbruck — [3]Physics Department and NanoLund, Lund University, — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck

Determining the conditions under which the most general class of quantum measurements (positive operator-valued measures (POVMs)), outperform projective measurements remains a challenging and largely unresolved problem. Of particular interest are projectively simulable POVMs which offer no advantage over projective schemes, as they can be realized through probabilistic mixtures of projective measurements. Characterizing the boundary between simulable and non-simulable POVMs is, however, a difficult task, and existing tools either fail to scale efficiently, provide limited experimental feasibility or work only for specific POVMs. Here, we introduce a general method to certify non-simulability of a POVM by constructing non-simulability witnesses and demonstrate how to make them robust against state preparation errors in experiments.

QI 15.3 Thu 10:00 BEY/0137

Entanglement detection close to Dicke states with many-body correlations — •Géza Tóth[1,2,3,4], Martin Quensen[5,6], Mareike Hetzel[5,6], Luis Santos[5], Augusto Smerzi[7,8,9], Luca Pezzè[7,8,9], and Carsten Klempt[5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, 48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), 20018 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Spain — [4]HUN-REN Wigner Research Centre for Physics, 1525 Budapest, Hungary — [5]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [6]Institut für Satellitengeodäsie und Inertialsensorik (DLR-SI), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), 30167 Hannover, Germany — [7]Instituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche (INO-CNR), 50125 Firenze, Italy — [8]European Laboratory for Nonlinear Spectroscopy (LENS), 50019 Sesto Fiorentino, Italy — [9]Quantum Science and Technologies in Arcetri (QSTAR), 50125 Firenze, Italy

We will review methods for detecting multipartite entanglement in an ensemble of spin-1/2 atoms with collective measurements. We will introduce entanglement criteria based on the measurement of many-body correlations, such as the parity. Interestingly, such criteria can detect a larger entanglement depth in some practical situations than previous methods. In an experimental application, our criteria require a single-particle resolution in measuring the particle number.

QI 15.4 Thu 10:15 BEY/0137

Higher-dimensional information lattice: Quantum state characterization through inclusion-exclusion local information — •Claudia Artiaco — Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

The information lattice provides a universal characterization of quantum many-body states through local information. Local information quantifies the total amount of correlations in a region on a given scale that cannot be found in any smaller subregion. This framework allows us to define the intrinsic correlation length scales of many-body states. Moreover, within the information lattice, the total information in a system becomes akin to a hydrodynamic quantity with well-defined local densities and local currents, which allow us to characterize quench dynamics and develop efficient approximate methods for the time evolution of large-scale many-body systems.

However, the original information lattice is strictly valid only for one-dimensional states, and its key properties, such as locality and the conservation of local information under unitary dynamics, do not easily extend to higher dimensions. In this talk, I will discuss these challenges and introduce a higher-dimensional generalization of the information lattice based on the inclusion-exclusion principle. I will show how this approach enables the characterization of two-dimensional states in different universality classes, including Anderson localized states, gapped states with critical boundaries, and ground states of the toric code in various geometries. I will further demonstrate how topological features can be interpreted in terms of inclusion-exclusion local information.

QI 15.5 Thu 10:30 BEY/0137

Remote quantum certification from prepare-measure correlations: theory and experiment — •Albert Rico[1], Javier Fernandez[2], Anna Sanpera[2], Some Sankar[2], and Adam Valles[2] — [1]University of Siegen — [2]Universitat Autonoma de Barcelona

For the practical implementation of quantum protocols, it is essencial to verify the presence of quantumness from classically observable data, under realistic assumptions. In a recent work, we demonstrated how this can be done in theory and experiment from the correlations between the inputs and outputs of a prepare-measure quantum setup, under the assumption that our quantum devices are limited in operational dimension and memory. Our contributions are: (1) we derive an inequality for the classical dimension needed to reproduce anti-correlated probability distributions; (2) we show that this inequality can be saturated, and this event displays quadratic quantum advantage with respect to classical siulation; (3) we prove that there is a unique strategy saturating the inequality, and thus find a method to self-test SIC-POVMs; (4) we engineer a certification protocol with low experimental error; and (5) we perform this method experimentally with orbital angular momentum with noise tolerance, thus certifying quantumness in practice. In this talk we will summarize the main ingredients of prepare-measure setup under consideration, sketch the results presented, and explain their implications in practical remote quantum certification for distant communication protocols.

QI 15.6 Thu 10:45 BEY/0137

Computable measures of fermionic non-Gaussianity — Poetri Sonya Tarabunga[1,2], Bernhard Jobst[1,2], Sheng-Hsuan Lin[3], Marc Langer[1,2], •Raúl Morral-Yepes[1,2], Barbara Kraus[1,2], and Frank Pollmann[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Quantinuum, Leopoldstrasse 180, 80804 Munich, Germany

Quantum many-body states generally cannot be efficiently simulated on classical computers. However, certain classes of states with special structure admit efficient representations and simulations. Among these, fermionic Gaussian states are fully characterized by their two-point correlation functions. In this work, we investigate two measures of fermionic non-Gaussianity, which quantify how close a given state is to being Gaussian: the occupation number entropy, defined in terms of the eigenvalues of the correlation matrix, and the natural orbital Rényi entropy, given by the participation entropy in the basis that diagonalizes the correlation matrix. We present efficient methods to compute these quantities and analyze their connection to classical simulability and the complexity of state preparation. Additionally, we prove the monotonicity of these measures under specific conditions. Finally, we demonstrate their behavior in several models.

30min. break

Invited Talk QI 15.7 Thu 11:30 BEY/0137

Robust shadow tomography: from quantum simulation to high-energy physics — •Hai-Chau Nguyen — University of Siegen, Siegen, Germany

Starting with a brief introduction to shadow tomography, we show that it can be reformulated in terms of generalised measurements. On the one hand, this allows for taking into account the measurement errors in the implementation of shadow tomography in a canonical way. On the other hand, the symmetry of a shadow tomography protocol can be investigated in parallel with the symmetry of its associated generalised measurement, revealing its robustness against even complex measurement noise. We then show that measurement errors in shadow tomography can be efficiently mitigated even when they are correlated. This can be achieved by effectively symmetrising the shadow tomography protocol through simple controlled randomised (qu)bit flips, which provides a simple and robust protocol in comparison to those that are more demanding, such as protocols based on sampling Clifford gates. While the theory of shadow tomography and its technical developments were motivated by applications in quantum simulators, we emphasise its more general conceptual implications. In particular, we demonstrate a natural application of shadow tomography in the characterisation of relativistic spin-spin correlations of output particles in high-energy physics experiments. As a concrete example, we discuss how shadow tomography can shed light on conceptual aspects of the recent experiments demonstrating top-quark entanglement at ATLAS and CMS.

QI 15.8 Thu 12:00 BEY/0137

Detection of many-body entanglement partitions in a quantum computer — Albert Rico[1,2], Dmitry Grinko[3,4,5], •Robin Krebs[6], and Lin Htoo Zaw[7] — [1]Quantum information Group, Autonomous University of Barcleona, Spain — [2]Theoretische Quantenoptik, Universität Siegen, Germany — [3]QuSoft, Amsterdam, Netherlands — [4]Institute for Logic, Language and Computation, University of Amsterdam, Netherlands — [5]Korteweg-de Vries Institute for Mathematics, University of Amsterdam, Netherlands — [6]Quantum Computing, Technische Universität Darmstadt, Germany — [7]Centre for Quantum Technologies, National University of Singapore, Singapore

We present a method to detect entanglement partitions of multipartite quantum systems, by exploiting their inherent symmetries. Structures like genuinely multipartite entanglement, m-separability and entanglement depth are detected as special cases. This formulation enables us to characterize all the entanglement partitions of all three- and fourpartite states and witnesses with unitary and permutation symmetry. In particular, we find and parametrize a complete set of bound entangled states therein. For larger systems, we provide a large family of analytical witnesses detecting many-body states of arbitrary size where none of the parties is separable from the rest. This method relies on weak Schur sampling with projective measurements, and thus can be implemented in a quantum computer. Beyond physics, our results apply to mathematics: we establish new inequalities between matrix immanants, and characterize the set of such inequalities for matrices of size three and four.

QI 15.9 Thu 12:15 BEY/0137

k-body correlations of graph states — •Mengying Hu[1,2], Elisa Monchietti[2], Ismaël Septembre[2], Kenneth Goodenough[2], Raphaël Mothe[2], and Otfried Gühne[2] — [1]School of Mathematical Sciences, Hebei Normal University, Shijiazhuang 050024, China — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany

Graph states play a key role in quantum information processing tasks, for instance quantum computing and quantum error correction. Understanding their intrinsic structure is fundamental for assessing their usefulness in computational or informational tasks. In particular, graph states are stabilizer states, meaning they can be uniquely defined by the group of local Pauli operators stabilizing them. Here, we study the groups that arise after deleting certain subsets of qubits from the stabilizer group, which we use to capture the k-body correlations of graph states, and we use these correlations as invariants to distinguish graph states up to local unitaries.