QI 5: Entanglement Theory

Time: Monday 15:00–18:00 Location: HFT-FT 101

Invited Talk QI 5.1 Mon 15:00 HFT-FT 101

Multi-copy activation of genuine multipartite entanglement in continuous-variable systems — Klára Baksová[1], Olga Leskovjanová[2], Ladislav Mišta[2], •Elizabeth Agudelo[1], and Nicolai Friis[1] — [1]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [2]Department of Optics, Palacký University, 17. Listopadu 12, 771˜46 Olomouc, Czech Republic

In multipartite systems, entanglement takes various forms. Some mixed states show entanglement across every possible cut of a multipartite system, though they originate from separable states in different partitions. Genuine multipartite entangled (GME) states, not formed by mixing partition-separable states, are intriguing. Advances in quantum tech raise questions about this framework when multiple state copies are accessible. States in finite dimensions are GME-activatable if they are not partially separable across any one bipartition, likely true for infinite dimensions too. We explore this in the continuous-variable context, providing GME-activatable non-Gaussian state examples. For Gaussian states, using a biseparability criterion for the covariance matrix, we find it fails to detect GME activation. We find fully inseparable Gaussian states that meet this criterion but can still be GME, showing the criterion's insufficiency for Gaussian states. To the best of our knowledge, there is no documented instance of a Gaussian state that is both fully inseparable and definitively biseparable, highlighting a gap in our current understanding of these particular quantum systems.

QI 5.2 Mon 15:30 HFT-FT 101

General class of continuous variable entanglement criteria — Martin Gärttner[1,2,3,4], •Tobias Haas[5], and Johannes Noll[3] — [1]Institut für Theoretische Physik, Universität Heidelberg, Germany — [2]Physikalisches Institut, Universität Heidelberg, Germany — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [4]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Jena — [5]Centre for Quantum Information and Communication, Université libre de Bruxelles, Belgium

We present a general class of entanglement criteria for continuous variable systems. Our criteria are based on the Husimi Q-distribution and allow for optimization over the set of all concave functions rendering them extremely general and versatile. We show that several entropic criteria and second moment criteria are obtained as special cases. Our criteria reveal entanglement of families of states undetected by any commonly used criteria and provide clear advantages under typical experimental constraints such as finite detector resolution and measurement statistics.

Based on PRL 131, 150201 and PRA 108, 042410.

QI 5.3 Mon 15:45 HFT-FT 101

Concurrence of entangled states in $d \times d$ dimensions with relaxed axisymmetry — •Juan Arnaudas[1] and Jens Siewert[2,3] — [1]BCAM - Basque Center for Applied Mathematics, E-48009 Bilbao, Spain — [2]University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [3]Ikerbasque, Basque Foundation for Science, E-48013 Bilbao, Spain

Families of highly symmetric states are an interesting playground for entanglement theory, because sometimes an exact solution to the entanglement problem is possible for them. This way they reveal the structure of the space of entangled states and may serve as a benchmark for other methods, e.g., for entanglement witnesses. An interesting example of such a family are the bipartite states with relaxed axisymmetry, in particular, because a fraction of them are entangled with a positive partial transpose (PPT). For a facet of this family the separability problem could be solved for any finite dimension d [1], and for $d = 3$ a numerically exact solution for the concurrence was presented [2], thereby exactly quantifying also the PPT entanglement. In this work we explore the possibility of analytically proving the $d = 3$ result and to extend it to higher dimensions.

[1] M. Seelbach Benkner *et al.*, Phys. Rev. A **106**, 022415 (2022).

[2] G. Sentís *et al.*, Phys. Rev. A **94**, 020302(R) (2016).

QI 5.4 Mon 16:00 HFT-FT 101

Alternatives of entanglement depth and metrological bounds — •Szilárd Szalay[1] and Géza Tóth[1,2] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]UPV/EHU, Bilbao, Spain

We work out the general theory of one-parameter families of partial entanglement properties, and the resulting entanglement depth like quantities. Special cases of these are the depth of partitionability, the depth of producibility (or simply entanglement depth) and the depth of stretchability, based on one-parameter families of partial entanglement properties known earlier. We also construct some further, physically meaningful cases, for instance the squareability, the toughness, and the degree of freedom. Metrological bounds on multipartite entanglement in terms of the quantum Fischer information fit naturally into this framework. Here we formulate these in terms of the depth of squareability, which therefore turns out to be the natural choice, leading to stronger bounds than the usual entanglement depth. We also formulate convex roof bounds for both cases, being much stronger than the direct ones.

QI 5.5 Mon 16:15 HFT-FT 101

Multipartite entanglement and the structure constants of Lie algebras — Satoya Imai[1,2], •Sophia Denker[1], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]QSTAR, INO-CNR, and LENS, Largo Enrico Fermi, 2, 50125 Firenze, Italy

Entanglement is an important resource in quantum information processing. Therefore, its detection and investigation are crucial tasks, too. In this contribution we present traceless operators based on the symmetric and antisymmetric structure constants of Lie algebras and explore their relation to trace polynomials. It turns out that these observables are useful for multipartite entanglement detection and, moreover, are linked to permutation-based entanglement witnesses. Further, we find that they are connected to projectors on highly entangled sub-spaces, which makes them strong entanglement criteria for high-dimensional tripartite systems.

15 min. break

QI 5.6 Mon 16:45 HFT-FT 101

Multiplexing and Information Transport in Quantum Networks — •Julia Freund, Alexander Pirker, and Wolfgang Dür — Insitute for Theoretical Physics, Innsbruck, Austria

The concepts of multiplexing and transport of quantum data are vital in quantum information such as quantum networks, distributed quantum metrology and computing. We focus on graph states due to their key role as multipartite-entangled resource states for example in measurement-based quantum computation or entanglement-based quantum networks. To manipulate the resource state for data transport and multiplexing, we utilize local Clifford operations, Pauli measurements and classical communication. The manipulation strategies we provide allow to extract and transport multiplexed Bell pairs, GHZ states and one-dimensional cluster states within a two-dimensional cluster state resource. Furthermore, our strategies maintain connectivity in the remaining graph state while being efficient in terms of required manipulations.

QI 5.7 Mon 17:00 HFT-FT 101

Absolute separability witnesses for symmetric multiqubit states — •Eduardo Serrano Ensástiga, Jérôme Denis, and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, B-4000 Liège, Belgium

Entanglement is a valuable resource for quantum applications, and a well-established method for creating entangled multiqubit symmetric states in a controlled manner is the application of a global unitary operation. However, certain states, called symmetric absolutely separable (SAS), remain unentangled after any unitary gate preserving permutation invariance in the constituents of the system. In this work, we develop criteria for detecting SAS states of any number of qubits [1,2]. Our approach is based on the Glauber-Sudarshan P representation for finite-dimensional quantum systems. We introduce families of linear and non-linear SAS witnesses formulated respectively as algebraic inequalities or a quadratic optimization problem. These witnesses are capable of identifying more SAS states than previously known counterparts [3].

[1] E. Serrano-Ensástiga, and J. Martin, Maximum entanglement of

mixed symmetric states under unitary transformations, SciPost Phys. 15, 120 (2023).

[2] E. Serrano-Ensástiga, J. Denis and J. Martin, Absolute separability witnesses for symmetric multiqubit states, too appear on arXiv soon.

[3] F. Bohnet-Waldraff, O. Giraud, and D. Braun, Absolutely classical spin states, Phys. Rev. A 95, 012318 (2017).

QI 5.8 Mon 17:15 HFT-FT 101

Number-phase uncertainty relations and bipartite entanglement detection in spin ensembles — •Giuseppe Vitagliano[1], Matteo Fadel[9], Iagoba Apellaniz[2], Matthias Kleinmann[3], Bernd Lücke[4], Carsten Klempt[4,5], and Geza Toth[2,6,7,8] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna 1020, Austria — [2]UPV/EHU, ES-48080 Bilbao, Spain — [3]Universität Siegen, DE-57068 Siegen, Germany — [4]Leibniz Universität Hannover, DE-30167 Hannover, Germany — [5]DLR-SI, DE-30167 Hannover, Germany — [6]DIPC, ES-20080 San Sebastian, Spain — [7]IKERBASQUE, ES-48011 Bilbao, Spain — [8]Wigner Research Centre for Physics, HU-1525 Budapest, Hungary — [9]ETH Zürich, CH-8093 Zürich, Switzerland

We present a method to detect bipartite entanglement and EPR steering based on number-phase-like uncertainty relations in split spin ensembles. In particular, we show how to detect bipartite entanglement in an unpolarized Dicke state of many spin-1/2 particles. We demonstrate the utility of the criteria by applying them to a recent experiment given in K. Lange et al. [Science 360, 416 (2018)]. Our methods also work well if split spin-squeezed states are considered. We discuss how to handle experimental imperfections.

[1] G. Vitagliano et al., Quantum 7, 914 (2023)

QI 5.9 Mon 17:30 HFT-FT 101

Sequential Weak Measurements for Generating Multipartite Entangled States — •Trinidad B. Lantaño, Dayou Yang, Koenraad Audenaert, Susana Huelga, and Martin Plenio — Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm 89069, Germany

We propose a state preparation protocol based on sequential measurements of a central spin coupled with a spin ensemble, and investigate the usefulness of the generated multi-spin states for quantum enhanced metrology. Remarkably, our protocol allows for the generation of highly entangled spin states, devoid of the necessity for non-linear spin interactions. The metrological sensitivity of the resulting state surpasses the standard quantum limit, reaching the coveted Heisenberg limit under symmetric coupling strength conditions. Additionally, we study the relevant case where coupling strengths are not symmetric, obtaining a specific time length for the preparation protocol where optimal sensitivity is achieved. Our results establish a new approach for the generation of large-scale, entangled states for quantum enhanced metrology within current experimental capabilities.

QI 5.10 Mon 17:45 HFT-FT 101

Topological entanglement duality in magnon systems — •Vahid Azimi Mousolou — Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden.

Recent progress has demonstrated that magnons provide a promising platform for quantum information processing technologies, offering potential energy efficiency compared to other counterparts. One notable advantage is the strong and intrinsic entangling property of magnons in magnetic materials [1-5]. Here, we present a topological duality in magnetic materials based on magnon entanglement.

[1] V. Azimi-Mousolou et al., Phys. Rev. B 108, 094430 (2023). [2] Y. Liu et al., New J. Phys. 25, 113032 (2023). [3] V. Azimi-Mousolou et al, Phys. Rev. A 106, 032407 (2022). [4] V. Azimi-Mousolou et al, Phys. Rev. B 104, 224302 (2021). [5] V. Azimi-Mousolou at al, Phys. Rev. B 102, 224418 (2020).