QI 21: Quantum Information: Concepts and Methods III

Time: Friday 9:30–12:45 Location: BEY/0245

Invited Talk QI 21.1 Fri 9:30 BEY/0245

Non-Hermitian topology and directional amplification — •Clara Wanjura — Max Planck Institute for the Science of Light, Staudtstraße 2, Erlangen

Topology has been a major research theme in condensed matter physics and is associated with a number of remarkable phenomena such as robust edge states. More recently, topology started to be investigated in systems experiencing gain and loss, sparking the field of non-Hermitian topology. However, for a long time, a clear observable signature of non-Hermitian topology had been lacking.

We recently closed this gap and showed that non-trivial, non-Hermitian topology is in one-to-one correspondence with the phenomenon of directional amplification in one-dimensional driven-dissipative systems, e.g., cavity arrays. Directional amplification allows to selectively amplify signals depending on their propagation direction and has attracted much attention as key resource for applications, such as quantum information processing. We experimentally demonstrated this connection between non-Hermitian topology and directional amplification in a cavity optomechanical system as well as realised a sensor based on non-Hermitian topology for which the sensitivity is exponentially enhanced with increasing system size.

Our work opens up new routes for the design of multimode robust directional amplifiers and novel topological sensors that can be integrated in scalable platforms such as superconducting circuits, cavity optomechanical systems, plasmonic waveguides and nanocavity arrays.

QI 21.2 Fri 10:00 BEY/0245

Graph-State Gates as Scrambling Primitives: Entanglement Growth and Complexity in Quantum Circuits — •Zahra Raissi[1], Himanshu Sahu[2], Mario Flory[3], and Aranya Bhattacharya[4] — [1]Paderborn University, Germany — [2]Perimeter Institute, Canada — [3]Jagiellonian University, Poland — [4]University of Bristol, UK

Understanding how quantum information spreads in many-body systems is central to quantum simulation, error correction, and quantum network design. In this work, we investigate structured random circuits built from graph-state gates, where small multi-qubit graph states are repeatedly embedded into a one-dimensional Clifford circuit at random locations. Each gate acts on a fixed number of qubits but carries an internal graph structure, allowing us to disentangle the role of local graph geometry from that of global circuit architecture.

Within this model, we use stabilizer methods to compute bipartite entanglement entropies, height functions, and light-cone diagnostics based on both Pauli spreading and out-of-time-order correlators (OTOCs). We find that the entanglement growth rate and saturation time are strongly correlated with two graph-theoretic features: a local light-cone capacity (degree and connectivity) and a cross-entanglement capacity (edge cuts/height). This reveals a hierarchy of graph-state gates according to their entangling and scrambling power. Our results provide a graph-theoretic design principle and a concrete ranking for selecting small graph blocks that optimize entanglement generation and operator spreading in Clifford quantum circuits.

QI 21.3 Fri 10:15 BEY/0245

Analysis of multi-detector quantum measurements via their cross-correlation polyspectra — •Armin Ghorbanietemad, Markus Sifft, and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI, Germany

Recent work has shown that higher-order spectra of continuous quantum measurement records provide characteristic fingerprints of stochastic system dynamics. These polyspectra capture essential features of measurement processes in platforms as diverse as nanotransport, single-photon emission from quantum dots, and spin-noise spectroscopy [1 - 3]. This makes them a more versatile analysis tool than traditional approaches such as full counting statistics or Langevin-based methods. The framework naturally incorporates measurement-induced damping, detector backaction, and the quantum Zeno effect. Key system parameters can be extracted by comparing experimental polyspectra with their analytical counterparts [2].

Here, we extend our single-detector theory to the case of multiple observables monitored simultaneously. We derive general expressions for spectra up to fourth order, apply the formalism to a coupled quantum system, and present a GPU-accelerated implementation that enables efficient computation of cross-correlation polyspectra from arbitrary Liouvillians.

[1] Hägele et al., PRB 98, 205143 (2018)
[2] Sifft et al., PRR 3, 033123 (2021)
[3] Sifft et al., PRA 109, 062210 (2024)

QI 21.4 Fri 10:30 BEY/0245

Characterizing genuine multipartite high-dimensional entanglement with the partition rank — •Sophia Denker[1], Ismaël Septembre[1], Robin Krebs[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Technische Universität Darmstadt, Darmstadt, Germany

Entanglement is an important resource in quantum information as it has been demonstrated to bring advantages in several applications. In fact, these advantages are even higher when going to larger systems, i. e. increasing the number of particles or their local dimensions. However, with increasing system size also the characterization and quantification of quantum entanglement becomes more complex.

We introduce a new measure for the entanglement dimensionality of multiparticle states, based on the partition rank. The partition rank is given by the number of biseparable terms, needed to decompose a multipartite quantum state. Different from the Schmidt decomposition the terms appearing here are allowed to be separable with respect to different bipartitions, making this approach a truly multipartite quantification. We translate the problem of finding the closest state with a certain partition rank to the problem of finding the closest product state, which is known as the geometric measure of entanglement. This translation allows us to tackle this new problem with well-established methods. Along the way, we identify quantum states which are maximally entangled with respect to this measure and further show that our methods could make a contribution towards solving an open problem in mathematics, related to the partition rank.

QI 21.5 Fri 10:45 BEY/0245

Analyzing Classical vs Quantum Temporal Correlations in Discrete-Time Counting Processes — •Bita Olamaei, Pharnam Bakhshinezhad, and Giuseppe Vitagliano — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, 1020 Vienna, Austria

We consider the problem of characterizing temporal sequences or outcomes arising from a quantum finite-state automaton process. This approach can be also seen as a relaxation of the original idea of Leggett and Garg of distinguishing classical from quantum temporal correlations based on macrorealist hidden-variable theories. The latter correspond essentially to automata with only one available state [1]. We focus on discrete-time counting processes and characterize the strength of temporal correlations via the probability of the "tick" event or via the Fano factor, that have been shown to have a nontrivial memory cost [2]. In particular, we look for the quantum d-state automaton model that can saturate the memory cost of the counting process, achieving either maximal probability of tick or maximal Fano factor, thereby characterizing the nature of the resource that, in particular, allows to surpass the performance of the analogous classical d-state automaton model.

[1]- C. Budroni and G. Vitagliano, Leggett-Garg macrorealism and temporal correlations, Phys. Rev. A. 107. 040101 (2023) [2]- C. Budroni, G. Vitagliano, and M. P. Woods, Ticking-clock performance enhanced by nonclassical temporal correlations, Phys. Rev. Res. 3, 033051 (2021)

30min. break

QI 21.6 Fri 11:30 BEY/0245

Measurement-induced transitions in fermionic systems — •Ihor Poboiko, Igor Gornyi, and Alexander D. Mirlin — Karlsruhe Institute of Technology, Karlsruhe, Germany

We develop a theory of measurement-induced phase transitions (MIPT) for d-dimensional lattice free fermions subject to random projective measurements of local site occupation numbers. In the limit of rare measurements, $\gamma \ll J$ (where γ is measurement rate per site and J is hopping constant), we derive a non-linear sigma model (NLSM) as an effective field theory of the problem. On the Gaussian level, valid in the limit $\gamma/J \to 0$, this model predicts "critical" (i.e. logarithmic enhancement of area law) behavior for the entanglement entropy. However, one-loop renormalization group analysis shows that for $d = 1$, the logarithmic growth saturates at a finite value $(J/\gamma)^2$ even for rare measurements, implying existence of a single area-law phase. The crossover between logarithmic growth and saturation, however, happens at an exponentially large scale, $\ln(l_{corr}) \sim J/\gamma$, thus making it easy to confuse with a transition in a finite-size system. Furthermore, utilizing ε-expansion, we demonstrate that the "critical" phase is stabilized for $d > 1$ with a transition to the area-law phase at a finite value of γ/J. The analytical calculations are supported by and are in excellent agreement with the extensive numerical simulations for $d = 1, 2$.

QI 21.7 Fri 11:45 BEY/0245

Efficient Entanglement Quantification with a Graph Neural Network — •Susanna Bräu, Martina Jung, and Martin Gärttner — Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena

Entanglement is a fundamental feature of quantum mechanics, yet quantifying it - using measures such as entanglement entropy - generally requires reconstruction of the full quantum state. However, this is infeasible for larger systems, limiting the accessible system sizes. In this work, we predict quantum correlation measures for many-body spin systems from measurement snapshots with a supervised machine learning approach, avoiding full quantum state tomography. Our approach uses a permutation-invariant graph neural network (GNN), which scales linearly with the system size. To improve the scaling with the number of snapshots, we implemented a mini-set architecture, that divides the input into smaller subsets processed in parallel. This modified architecture enables entanglement prediction for larger data sets, potentially allowing for more accurate predictions than the traditional architecture without increasing the number of parameters in the network significantly. Furthermore, we aim to extend the approach from quantum many-body systems to continuous variable systems.

QI 21.8 Fri 12:00 BEY/0245

Chaotic melting of superconducting quantum chips: Quantum chaos in effective Hamiltonians — •Lucas Resch and Juan Diego Urbina — University of Regensburg

Superconducting qubits, in particular transmons, are at the forefront of quantum computing research [1]. Recent studies have revealed signatures of chaos near the ground state in these systems, challenging the conventional view that chaotic behavior emerges only at high energies [2]. In this work, we analyze spectral statistics, the inverse participation ratio, and the Lyapunov exponent to characterize this chaotic regime. Our results indicate that the observed chaotic features can be attributed to virtual interactions between computational states within an effective low-energy subspace and non-computational states outside it. This reinterpretation clarifies the origin of chaos in transmon-based architectures and provides a framework for understanding its implications for quantum control and device performance.

References

[1] J. M. Gambetta et al., *Building logical qubits in a superconducting quantum computing system,* npj Quantum Information 3, 2 (2017). [2] S. Börner et al., *Classical chaos in quantum computers,* Phys. Rev. Research 6, (2024).

QI 21.9 Fri 12:15 BEY/0245

Stabilizing Rényi entropy and entanglement distributions in unitary random circuits — Dominik Szombathy[1,2], Angelo Valli[1], Catalin Pascu Moca[3], Janos Asboth[1], Lorant Farkas[2], Tibor Rakovszky[1], and •Gergely Zarand[1] — [1]Budapest University of Technology and Economics, Budapest (Hungary) — [2]Nokia Bell Labs, Budapest (Hungary) — [3]University of Oradea, Oradea (Romania)

Entanglement and nonstabilizerness (or "magic") are instrumental in characterizing quantum complexity. While entanglement is related to the "quantumness" of a state, it is not exhaustive, as Clifford circuits generate highly entangled states but can be efficiently simulated classically. This lack of complexity is encoded in their peculiar spectral properties. Stabilizer Rényi entropy quantifies non-Clifford resources required to prepare a quantum state and is pivotal for achieving quantum advantage. These resources are related, yet their interplay is largely unexplored. We characterize entanglement and magic generation through their distributions, obtained by numerically sampling Clifford+T and Haar-random unitary circuits. For N qubits, the distributions are highly concentrated around typical values of entanglement (N/2 plus a quantum correction) and magic (N-2), which are not independent. However, we demonstrate that their fluctuations are asymptotically independent: both the covariance and mutual information of the joint entanglement-magic distribution vanish exponentially with system size.

Szombathy et al. PRR 7, 043080 (2025); PRR 7, 043072 (2025)

QI 21.10 Fri 12:30 BEY/0245

Quantitative bound entanglement in the Horodecki two-qutrit states — Gael Sentis[1] and •Jens Siewert[2,3] — [1]Grup d'Informació Quàntica, Universitat Autònoma de Barcelona, Barcelona, Spain — [2]University of the Basque Country and EHU Quantum Center, Bilbao, Spain — [3]Ikerbasque, Basque Foundation of Science, Bilbao, Spain

In 1999, Horodecki *et al.* [1] introduced a one-parameter family of two-qutrit states that has since become an archetypal example of entangled states with a positive partial transpose (PPT). PPT states are typically highly mixed, and their entanglement is widely regarded as rather weak. Yet the actual degree of this weakness has remained unclear. In Ref. [2], we provided a numerically exact solution for the linear entropy of the Horodecki two-qutrit PPT-entangled states. However, this result has limited practical relevance, as linear entropy is not commonly used in entanglement quantification, and no approximate analytical expression is known. In the present contribution, we investigate whether an exact formula for the concurrence of this emblematic family of states can be obtained.

[1] P. Horodecki, M. Horodecki, and R. Horodecki, Phys. Rev. Lett. **82**, 1056 (1999).

[2] G. Sentís, C. Eltschka, and J. Siewert, Phys. Rev. A **94**, 020302(R) (2016).