QI 12: Quantum Foundations

Time: Wednesday 15:00–18:00 Location: BEY/0137

QI 12.1 Wed 15:00 BEY/0137

On the Dynamics of Local Hidden-Variable Models — •Nick von Selzam[1,2] and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg

Bell nonlocality is an intriguing property of quantum mechanics with far reaching consequences for information processing, philosophy and our fundamental understanding of nature. However, nonlocality is a statement about static correlations only. It does not take into account dynamics, i.e. time evolution of those correlations. Consider a dynamic situation where the correlations remain local for all times. Then at each moment in time there exists a local hidden-variable (LHV) model reproducing the momentary correlations. Can the time evolution of the correlations then be captured by evolving the hidden variables? In this light, we define dynamical LHV models and motivate and discuss a wide range of physical and mathematical assumptions. Based on a simple counter example we conjecture that such LHV dynamics does in general not exist. This is further substantiated by a rigorous no-go theorem. Our results suggest a new type of dynamical nonlocality expressed by the quantum time evolution of local correlations.

QI 12.2 Wed 15:15 BEY/0137

Today's Experiments Suffice to Verify the Quantum Essence of Gravity — •Martin Plávala — Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany

The gravity-mediated entanglement experiments employ concepts from quantum information to argue that if gravitational interaction creates entanglement between two systems, then gravity cannot be described by a classical system. However, the proposed experiments remain beyond out current technological capability, with optimistic projections placing the experiment outside of short-term future. Here we leverage quantum information techniques to argue that current matter-wave interferometers are sufficient to indirectly prove that gravitational interaction creates entanglement between two systems. Specifically, we prove that if we experimentally verify the Schrödinger equation for a single delocalized system interacting gravitationally with an external mass, then the time evolution of two delocalized systems will lead to gravity-mediated entanglement. Our findings indicate that the experimental verification of the quantum essence of gravity is on the horizon.

QI 12.3 Wed 15:30 BEY/0137

Paradox-free classical non-causality and unambiguous nonlocality without entanglement are equivalent — Hippolyte Dourdent[1], Kyrylo Simonov[2], •Andreas Leitherer[1], Emanuel-Cristian Boghiu[2], Ravi Kunjwal[3], Saronath Halder[4], Remigiusz Augusiak[4], and Antonio Acín[1,5] — [1]ICFO-Institut de Ciències Fotòniques — [2]Fakultät für Mathematik, Universität Wien — [3]Aix-Marseille University, CNRS, LIS — [4]Center for Theoretical Physics, Polish Academy of Sciences — [5]ICREA - Institució Catalana de Recerca i Estudis Avançats

Definite causal order is an intuitive assumption which can, however, be violated without introducing paradoxes such as the grandfather antinomy. Interestingly, it is not necessary to invoke quantum or more exotic physics: process functions generalize classical deterministic communication by relaxing the assumption of a fixed causal structure between local operations. Previous work demonstrated that for three-parties, non-causal process functions can distinguish qubit product bases that cannot be realized by local operations and classical communication - a phenomenon known as quantum nonlocality without entanglement (QNLWE). We significantly elevate this result for any dimension and any number of parties, establishing an equivalence between the unique fixed-point condition characterizing process functions and a simple "unambiguity" condition, requiring that local parties perform local disjoint operations. We refine previous characterizations of process functions and demonstrate how to construct non-causal process functions from unambiguous QNLWE product bases and vice versa.

QI 12.4 Wed 15:45 BEY/0137

Generalised Quantum Dynamics under Operational Constraints — •Joel Huber and Matthias Kleinmann — Universität Siegen

Generalised phase space theories can be considered to study potential deviations from quantum time evolution given by the Schrödinger equation. In the phase space formulation, quantum dynamics is governed by the Moyal bracket. We consider generalisations thereof and impose operational conditions – such as probability positivity – to characterise consistent dynamics. We show how (generalised) quantum dynamics impacts the momentum and position distributions in the presence of a cubic potential, and argue that this effect is experimentally accessible. The consistency of a proposed evolution depends critically on both the bracket structure and the underlying state space. We analyse scenarios where the state space contains Gaussian states or the first excited state of the harmonic oscillator. In the case of ideal preparation of these states, phase space dynamics is strongly constrained and quantum dynamics is found to be the only consistent time-reversible evolution, at least to the order that can be probed in a cubic potential.

QI 12.5 Wed 16:00 BEY/0137

Phase space tableau simulation for quantum computation — •Selman Ipek[1], Cihan Okay[2], Atak Talay Yücel[3], Cagdas Ozdemir[4], and Farzad Shahi[2] — [1]Institut Für Theoretische Physik, Leibniz Universität Hannover — [2]Department of Mathematics, Bilkent University — [3]Department of Computer Engineering, Bilkent University — [4]Department of Physics, Bilkent University

We introduce a novel tableau-based classical simulation method for quantum computation, formulated within the phase space framework of the extended stabilizer theory of closed non-contextual operators. This method enables the efficient classical simulation of a broader class of quantum circuits beyond the stabilizer formalism. We implement the simulator and benchmark its performance on basic quantum algorithms, including the hidden shift and Deutsch-Jozsa algorithms.

QI 12.6 Wed 16:15 BEY/0137

Witnessing nonstabilizerness with Bell inequalities — Rafael Macêdo[1,2], •Patrick Andriolo[2,3,4], Santiago Zamora[1,2], Davide Poderini[2,5], and Rafael Chaves[2,6] — [1]Departamento de Física Teórica e Experimental, Universidade Federal do Rio Grande do Norte, 59078-970 Natal-RN, Brazil — [2]International Institute of Physics, Federal University of Rio Grande do Norte, 59078-970, Natal, Brazil — [3]Physics Institute, University of São Paulo, Rua do Matão, 1371, São Paulo, Brazil — [4]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [5]Università degli Studi di Pavia, Dipartimento di Fisica, QUIT Group, via Bassi 6, 27100 Pavia, Italy — [6]School of Science and Technology, Federal University of Rio Grande do Norte, 59078-970 Natal, Brazil

Non-stabilizerness is a fundamental resource for quantum computation, enabling quantum algorithms to surpass classical capabilities. Despite its importance, characterizing this resource remains challenging due to the intricate geometry of stabilizer polytopes and the difficulty of simulating non-stabilizer states. In this work, through device-independent considerations, we reveal an unexpected connection between non-stabilizerness and Bell inequalities. Although certain stabilizer states can already achieve maximal violations of specific Bell inequalities, we demonstrate that appropriately constructed Bell inequalities can nevertheless serve as witnesses of non-stabilizerness, revealing when a state lies beyond the stabilizer set. This uncovers a novel relationship between the device-independent framework and quantum computation. Phys. Rev. A 112, L050401.

30min. break

QI 12.7 Wed 17:00 BEY/0137

Beyond Mermin: Multipartite Bell Inequalities with Many Measurement Settings — •Fynn Otto[1], Junxiang Huang[2], Carlos de Gois[1,3,4], Xiao Yuan[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Peking University, Beijing, China — [3]Inria de Saclay, Palaiseau, France — [4]École polytechnique, Palaiseau, France

Nonlocal correlations in multipartite quantum systems are typically probed through Bell inequalities with only a few measurement settings, limiting the sensitivity of existing tests. Here we introduce a generalization of the Mermin inequality to an arbitrarily large number of measurement settings per party. This family of inequalities is maximally violated by Greenberger-Horne-Zeilinger states and substantially lowers the noise thresholds required to certify nonlocality and nonlocality depth. We further derive Bell inequalities capable of detecting genuine multipartite entanglement in broad classes of graph states. Finally, we discuss prospects for experimental implementations of these inequalities in state-of-the-art quantum platforms. Together, these advances expand the toolbox for probing the structure of quantum correlations and strengthen practical routes toward certifying entanglement in complex quantum systems.

QI 12.8 Wed 17:15 BEY/0137

A Causal-Modelling Reconstruction of Quantum Mechanics That Comes With its Own Interpretation — •Joppe Widstam — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We reconstruct quantum mechanics from intuitive causal-modelling principles for time-symmetric physics. In this reconstruction, the quantum state is a mere convenient mathematical object for agents able to control the initial conditions and who are able to choose what observable to measure.

QI 12.9 Wed 17:30 BEY/0137

The Quantum Rashomon Effect: A Strengthened Frauchiger-Renner Argument — •Jochen Szangolies — Deutsches Zentrum für Luft- und Raumfahrt, Köln

The Frauchiger-Renner argument aims to show that ‘quantum theory cannot consistently describe the use of itself’: in many-party settings where agents are themselves subject to quantum experiments, agents may make predictions that contradict observations. Here, we introduce a simplified setting using only three agents, that is independent of the initial quantum state, thus eliminating in particular any need for entanglement, and furthermore does not need to invoke any final measurement and resulting collapse. Nevertheless, the predictions and observations made by the agents cannot be integrated into a single, consistent account. We propose that the existence of this sort of Rashomon effect, i.e. the impossibility of uniting different perspectives, is due to failing to account for the limits put on the information available about any given system as encapsulated in the notion of an epistemic horizon.

QI 12.10 Wed 17:45 BEY/0137

Multiple solutions of the classical shooting problem: consistent histories and decoherence — •Julian Rettenberger-Zweck and Juan-Diego Urbina — Institut für theoretische Physik, Universität Regensburg, Regensburg, Germany

The *consistent histories* approach to quantum mechanics [1] provides a framework for defining whether a sequence of events occurring at different times—a *history*—exhibits emergent classical behavior. Specifically, a set of histories is called consistent if the off-diagonal elements of the decoherence functional, which quantify the interference between histories, vanish in an appropriate limit, leaving only the (properly normalized) classical probabilities on the diagonal [2]. The semiclassical (Van Vleck–Gutzwiller) propagator [3] consists of a coherent sum over all classical paths—or, in the language of consistent histories, all classical histories satisfying the specified boundary conditions—which enables a direct calculation of the decoherence functional. In this way, we explicitly evaluate the decoherence functional for two simple systems: the particle on a circle and the particle in a box, confirming the suppression of interference between distinct classical histories as well as the effect of decoherence within a Caldeira–Leggett approach [4].

[1] R. B. Griffiths, *J. Stat. Phys.* 36, 219 (1984).
[2] H. F. Dowker and J. J. Halliwell, *Phys. Rev. D* 46, 1580 (1992).
[3] M. C. Gutzwiller, *Chaos in Classical and Quantum Mechanics*, Springer, New York (1990).
[4] A. O. Caldeira and A. J. Leggett, *Physica A* 121, 587 (1983).