International Centre for Theory of Quantum Technologies | Uniwersytet Gdański | Centre for Quantum Optical Technologies | University of Warsaw

QUANTUMSPEEDUP

January 29th-31st, 2025, Gdańsk

Book of Abstracts

European Funds for Smart Economy | Republic of Poland | Co-funded by the European Union

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January 29th-31st, 2025, Gdańsk

Venue: University of Gdańsk, Faculty of Mathematics, Physics, and Informatics, Wita Stwosza street, 57, Gdańsk, Poland

Programme

Wednesday, January 29th, 2025	
12:00	Registration
14:00	**Official opening**
	Session I
14:15	**Marek Żukowski**
	QuantumSpeedUp at ICTQT
14:30	**Marcin Pawłowski**
	Quantum Cybersecurity Research
15:00	**Łukasz Rudnicki**
	Coarse-grained Quantum Technologies Research
15:30	Coffee break
	Session II
16:15	**Ana Belen Sainz**
	Theoretical Underpinnings of Quantum Technologies
16:45	**Marek Żukowski**
	Multiphoton Quantum Optics for Quantum Information, and more
17:15	**Michał Horodecki**
	Quantum thermodynamics at NQR&QT group and catalytic enhancement in thermal machines
18:00	Welcome reception

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Thursday, January 30th, 2025

10:30	**Organizational announcements**	
	Thursday SpeedTalk Sessions	
10:35 – 11:00	**SpeedTalks I**	
	Borhan Ahmadi (ICTQT, UG)	**Adamantia Zampeli** (ICTQT, UG)
	Marek Winczewski (WMFiI, UG)	**Rishav Sagar** (ICTQT, UG)
	Gerardo Suarez (ICTQT, UG)	**Karthik Hosapete Seshadri** (ICTQT, UG)
	Andre Hernandes Alves Malavazi (ICTQT, UG)	**Karol Horodecki** (WMFiI, UG)
	Break & Discussion time	
11:30 – 11:55	**SpeedTalks II**	
	Matthias Salzger (ICTQT, UG)	**Pedro Dieguez** (ICTQT, UG)
	Piotr Mironowicz (SU)	**Sebastian Borówka** (QOT, UW)
	Bartosz Kasza (QOT, UW)	**Mateusz Mazelnik** (QOT, UW)
	Giovanni Scala (INFN)	**Michał Parniak** (QOT, UW)
	Break & Discussion time	
12:25 – 12:50	**SpeedTalks III**	
	Beata Zjawin (ICTQT, UG)	**Konrad Schlichtholz** (ICTQT, UG)
	Wiktor Krokosz (QOT, UW)	**Tomasz Prokop** (QOT, UW)
	Moein Naseri (QOT, UW)	**Gabriel Ko** (QOT, UW)
	Lunch Break	
15:00 – 17:00	**Thursday Poster Session**	

Friday, January 31st, 2025

10:30	**Organizational announcements**	
	Friday SpeedTalk Sessions	
10:35 – 11:00	**SpeedTalks IV**	
	Antonio Mandarino (UNIMI)	**Sina Soltani** (ICTQT, UG)
	Marcin Markiewicz (ICTQT, UG)	**Amrapali Sen** (ICTQT, UG)
	Robert Okuła (GUT)	**Paweł Mazurek** (WMFiI, UG)
	Alexandre Orthey (IPPT, PAN)	**Felipe Barretto** (IFUSP)
	Break & Discussion time	
11:30 – 11:55	**SpeedTalks V**	
	Marcin Marciniak (WMFiI, UG)	**Vinicius Rossi** (ICTQT, UG)
	Marco Erba (ICTQT, UG)	**Luis Cort Barrada** (ICTQT, UG)
	Amit Te'eni (BIU)	**Akshata Shenoy** (ICTQT, UG)
	Sumit Rout (ICTQT, UG)	**Marcin Klaczak** (ICTQT, UG)
	Lunch Break	
14:00 – 16:00	**Friday Poster Session**	
16:00	Closing remarks	

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List of speed talks / poster sessions

Thursday Sessions	
Borhan Ahmadi (ICTQT, UG)	Super-Optimal Charging of Quantum Batteries via Reservoir Engineering
Marek Winczewski (WMFiI, UG)	Non-equilibrium Thermometry in The Strong Coupling Regime With Bosonic Sample and Probe
Gerardo Suarez (ICTQT, UG)	A CPTP map for Non-Markovian Open systems
Andre Hernandes Alves Malavazi (ICTQT, UG)	Weak measurement-based protocol for ergotropy protection in open quantum batteries
Paweł Mazurek (WMFiI, UG)	Charging Quantum Batteries by an Incoherent Source
Rishav Sagar (ICTQT, UG)	Weak measurement-based protocol for ergotropy protection in open quantum batteries
Karthik Hosapete Seshadri (ICTQT, UG)	Extreme violations of Leggett-Garg inequalities for a system subjected to indefinite temporal dynamics
Karol Horodecki (WMFiI, UG)	Quantification of energy consumption of quantum resource generation
Matthias Salzger (ICTQT, UG)	A decompositional framework for process theories in spacetime
Piotr Mironowicz (SU)	Optimization of experimental quantum randomness expansion
Bartosz Kasza (QOT, UW)	Fourier mode decomposition as a method for solving non-equilibrium steady states of fractured atomic loops for atomic microwave receiver
Giovanni Scala (INFN)	Robustness of chaotic-light correlation imaging against turbulence
Pedro Dieguez (ICTQT, UG)	Experimental demonstration of the equivalence of entropic uncertainty with wave-particle duality
Sebastian Borówka (QOT, UW)	All-optical receiving of weak microwave fields in room-temperature Rydberg atoms
Mateusz Mazelnik (QOT, UW)	Interactions-enhanced microwave sensing with Rydberg atoms
Michał Parniak (QOT, UW)	Rydberg atoms in space
Beata Zjawin (ICTQT, UG)	Activation of post-quantumness in bipartite generalised EPR scenarios
Wiktor Krokosz (QOT, UW)	Characterization of EHF band emitters using Rydberg atoms and metamaterials
Moein Naseri (QOT, UW)	Scalable noisy quantum circuits for biased-noise qubits
Konrad Schlichtholz (ICTQT, UG)	Superresolution in systems evolving under Brownian motion utilizing spatial mode demultiplexing
Tomasz Prokop (QOT, UW)	Optical beating frequency measurement with PLL
Gabriel Ko (QOT, UW)	Troubleshooting a weak vacuum optical cavity lock: A student's guide

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Friday Sessions	
Antonio Mandarino (UNIMI)	Study of Quantum Systems with Physics-Informed Neural Networks
Marcin Markiewicz (ICTQT, UG)	Relativistically invariant encoding of quantum information revisited
Robert Okuła (GUT)	Device-independent Shannon entropy certification
Alexandre Orthey (IPPT, PAN)	Geometric monotones of violations of quantum realism
Sina Soltani (ICTQT, UG)	Noncontextual ontological models of operational probabilistic theories
Amrapali Sen (ICTQT, UG)	Operational Analysis of Superluminal Observers
Adamantia Zampeli (ICTQT, UG)	Causality principle and its violation
Felipe Barretto (IFUSP)	A Geometrical Relation Between Noncontextuality and Quantum State Discrimination
Marcin Marciniak (WMFiI, UG)	On the structure of the cone of k-positive maps
Marco Erba (ICTQT, UG)	The composition rule for quantum systems is not the only possible one
Amit Te'eni (BIU)	Oracle problems as communication tasks and optimization of quantum algorithms
Sumit Rout (ICTQT, UG)	Randomness-free Detection of Non-projective Measurements: Qubits & beyond
Vinicius Rossi (ICTQT, UG)	Testing nonclassicality in a photonic processor
Luis Cort Barrada (ICTQT, UG)	Keldysh field theory for density matrix formalism with applications in quantum information processing
Akshata Shenoy (ICTQT, UG)	Quantum state tomography of pure three-qubit states from its parts
Marcin Klaczak (ICTQT, UG)	Quantum machine learning models for cancer detection
Marek Żukowski (ICTQT, UG)	Against (unitary) interpretation (of quantum mechanics): removing the metaphysical load

Acronyms

UG – University of Gdańsk
ICTQT – International Centre for Theory of Quantum Technologies
WMFiI - Department of Mathematics, Physics and Informatics
UW – University of Warsaw
QOT – Centre for Quantum Optical Technologies, Centre of New Technologies
CFT PAN – Center for Theoretical Physics, Polish Academy of Sciences
IPPT PAN - Institute of Fundamental Technological Research, Polish Academy of Sciences
BIU - Bar-Ilan University, Israel
IFUSP - Instituto de Física da Universidade de São Paulo, Brazil
INFN - Istituto Nazionale di Fisica Nucleare, Italy
UNIMI - University of Milan, Italy
SU - Stockholm University, Sweden

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Speakers

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Session I – 29/01/2025

QuantumSpeedUp at ICTQT

Marek Żukowski
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
This year the World celebrates 100th birthday of Quantum Mechanics. We shall enter the eight year of operation of ICTQT. QuantumSpeedUp is in a way a celebration of that. We have a new core funding grant, MAB FENG, the aims of which I shall shortly discuss. We are among first four MAB Centres to be awarded such a grant. The team of MAB groups leaders is now formed. Our research in quantum schemantum and new quantum technologies will speed up. Let us work together to once more prove that Gdańsk is an important point on the map of European quantum science.

Quantum Cybersecurity Research

Marcin Pawłowski
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
I present the main goals of QCC group and the motivation behind them. I also explain how we want to achieve them and discuss the ongoing projects.

Coarse-grained Quantum Technologies Research

Łukasz Rudnicki
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
We conduct research in metrology and aim at applicatioins in cryptography. We focus on protocols in which measurements of only a few parameters still allow for a very good performance in a setup that is conveniently implementable and scalable, despite the noise present in the system. For example, while quantum-optimal discrimination of two closely separated light sources can be achieved by ideal spatial-mode demultiplexing, we show that any imperfections of the demultiplexer make simple statistical tests practically useless. As a handy alternative, we propose simple semi-separation independent tests, depending on only one measured parameter, with asymptotically vanishing probability of making an error.

Session II – 29/01/2025

Theoretical Underpinnings of Quantum Technologies

Ana Belen Sainz
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
The quantum revolutions from last century left us with an amazing new toy to play with. How does it work? What can we use it for? In this talk I'll introduce you to the research activities of the "Theoretical Underpinnings of Quantum Technologies" group at ICTQT. I'll walk you through the kinds of questions we are interested in, the projects we have worked on in our 5 years of life, and how the new FENG-ICTQT will enable us to push our research forwards.

Multiphoton Quantum Optics for Quantum Information, and more

Marek Żukowski
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
The MQOQI group and its associates aim mainly at studying non-classical quantum phenomena, which could be useful in quantum communication and related areas. The focus is of course on quantum optical methods. We are interested in phenomena which could be observable in modern optical laboratories. We are also interested in debunking myths about quantum theory which rest on impossible to perform gedanken experiments.

Quantum thermodynamics at NQRQT group and catalytic enhancement in thermal machines

Michał Horodecki
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
We first briefly overview the quantum thermodynamics in NQRQT group. In particular we present some advances in numerical simulations of open systems. Next, we present results on catalytic enhancement in thermal machines. We demonstrate how the concept of a catalyst can be incorporated to enhance the performance of thermal machines. Here, the catalyst corresponds to a d-dimensional (possibly) degenerate quantum system that is restored at the end of each thermodynamic cycle. Specifically, within the model of two-stroke heat engines, we show that the optimal Otto efficiency 1-omega_c/omega_h can be extended to the generalized formula 1 - omega_c/ (d omega_h). This approach generalizes to other modes of operation, such as cooling processes or machines operating continuously (rather than in discrete strokes). An important practical application of this catalysis is in enhancing the qubit resetting process for quantum computing tasks, where it boosts qubit cooling without heating the catalyst during the protocol.

References:
Phys. Rev. Lett. 132, 260403(2024), Phys. Rev. E 110, 044120 (2024)

All the work presented in both sessions has been conducted as part of the project titled 'International Centre for Theory of Quantum Technologies 2.0: R&D Industrial and Experimental Phase' (contract no. FENG.02.01-IP.05-0006/23). The project is implemented as part of the International Research Agendas Programme of the Foundation for Polish Science, co-financed by the European Funds for a Smart Economy 2021-2027 (FENG), Priority FENG.02 Innovation-friendly environment, Measure FENG.02.01.

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SpeedTalk Speakers / Poster Presenters

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SpeedTalk Session I – 30/01/2025

Super-Optimal Charging of Quantum Batteries via Reservoir Engineering

Borhan Ahmadi
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
Energy dissipation, typically considered an undesirable process, has recently been shown to be harnessed as a resource to optimize the performance of a quantum battery. Following this perspective, we introduce a novel technique of charging in which coherent charger-battery interaction is replaced by a dissipative interaction via an engineered shared reservoir. We demonstrate that exploiting collective effects of the engineered shared reservoir allows for extra optimization giving rise to optimal redistribution of energy, which leads to a significant enhancement in the efficiency of the charging process. The article unveils the intricacies of built-in detuning within the context of a shared environment, offering a deeper understanding of the charging mechanisms involved. These findings apply naturally to quantum circuit battery architectures, suggesting the feasibility of efficient energy storage in these systems. Moreover, the super-optimal charging offers a practical justification for charger-battery configurations.

https://arxiv.org/abs/2407.16553

Non-equilibrium Thermometry in The Strong Coupling Regime With Bosonic Sample and Probe

Marek Winczewski
Faculty of Mathematics, Physics and Informatics, University of Gdańsk

Abstract:
We characterize the measurement sensitivity, quantified by the Quantum Fisher Information (QFI), of a thermometric probe of quantum harmonic oscillator (QHO) strongly coupled to the sample of interest, a bosonic bath at temperature T. For non-equilibrium protocols, in which the probe is measured before reaching equilibrium with the sample, new behavior of the measurement sensitivity arising due to non-Markovian dynamics is expected, as in the fermionic case [arXiv:2310:14655]. We investigate whether QFI rate is maximized at a finite interrogation time t^* as in fermionic case, or the solution $t^* \to 0$, known in the Markovian limit, is reproduced [Quantum 6, 869 (2022)].

A CPTP map for Non-Markovian Open systems

Gerardo Suarez
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
Open quantum systems undergo non-trivial evolution due to their coupling with their environment. One of the most popular descriptions for its dynamics namely the Gorini–Kossakowski–Lindblad-Sudarshan equation (GKLS) relies on a set of approximations, in particular, the rotating wave approximation and the Markov approximation. The first one clearly affects the accuracy of the description in both the transient and steady state regimes, while the second is more about the transient regime. The combination of both approximations will make both coherences and populations decay ``purely exponentially" meaning they just decay without any sort of increases. On the other hand letting go of any of the approximations takes us away from this ``purely exponentially" decaying regime. Most approaches that are able to describe the non-exponentially decaying part of open quantum systems suffer from negativity issues leading to unphysical results, in this talk we present a completely positive trace preserving map (CPTP) able to describe this regime.

https://arxiv.org/abs/2403.04488

Weak measurement-based protocol for ergotropy protection in open quantum batteries

Andre Hernandes Alves Malavazi
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
Quantum batteries are emerging as highly efficient energy storage devices that can exceed classical performance limits. Although there have been significant advancements in controlling these systems, challenges remain in stabilizing stored energy and minimizing losses due to inevitable environmental interaction. In this paper, we propose a protocol that employs selective weak measurements to protect quantum states from such influence and mitigate battery discharging. We establish thermodynamic constraints that allow this method to be implemented without disrupting the overall energy and ergotropy balance of the system. Our findings demonstrate that appropriately chosen measurement intensity can reduce unwanted discharging effects, thereby preserving ergotropy and improving the stability of quantum batteries. Additionally, we explore how weak measurements influence the coherent and incoherent components of ergotropy, providing new insights into the practical application of quantum coherence in energy storage technologies.

https://arxiv.org/abs/2411.16633

Causality principle and its violation

Adamantia Zampeli
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
In quantum theory, the principle of causality states that there should be no influence from the future to any experiment performed in the present and this is manifested in the probabilities. However, there are situations that this principle is violated both in non-relativistic quantum theory as well as the relativistic quantum field theory. Here, I discuss the theoretical assumptions behind this condition, its formulation in the histories formalism and when it is violated.

Catalyst Assisted Cooling

Rishav Sagar
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
Cooling qubits is challenging task in the development of quantum computers for practical purposes. We consider a target qubit and a qubit machine assisted by a catalyst to achieve catalytic advantage in the thermodynamic process. We show that using a catalyst, one can achieve catalytic advantage in two ways:
a) Extending the regime of operation and;
b) Better cooling performance as compared to non-catalytic scenario.

https://arxiv.org/abs/2411.16633

Extreme violations of Leggett-Garg inequalities for a system subjected to indefinite temporal dynamics

Karthik Hosapete Seshadri
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
The violation of Leggett-Garg Inequality (LGI) indicates general temporal correlations in quantum systems that can not be explained classically. Under unitary dynamics and projective measurements, the violation of LGI is restricted

up to the temporal Tsirelson's bound (TTB). Here, we consider superposition of unitary time evolutions and find them to produce an enhancement in the violation of LGI beyond the TTB, growing monotonically with increasing superposition. We experimentally realize superposition of unitaries in NMR systems and demonstrate this enhanced violation. In the presence of noise, such superposition of unitaries remarkably extend the time of LGI violation, showcasing improved robustness against decoherence. This opens up possibilities of using such nontrivial indefinite dynamical maps for robust quantum control, quantum metrology along with provoking research on characterizing correlations in the presence of time loops.

Quantification of energy consumption of quantum resource generation

Karol Horodecki
Faculty of Mathematics, Physics and Informatics, University of Gdańsk

Abstract:
One of the main tasks of quantum information processing is generating, manipulating, and using quantum resources. Prominent examples of such resources are quantum entanglement and quantum secret key, which are planned to be used in future quantum networks, e.g., for distributed quantum computing and secret communication, respectively. In these networks, quantum resources will be distributed via quantum channels. Due to channels imperfections, this process is expected to involve energy consumption. The consumption takes place during both passing input to the channel and the distillation of imperfect resources taken from the channel's output to its almost perfect form. For this reason, we propose estimating and minimizing this consumption as one of the important tasks on the way to resource aware quantum information processing.
We then establish a quantitative study of energy expenditure in producing quantum resources via quantum channels. We distinguish technological and fundamental energy costs. Technological cost depends on hardware; hence, it is not a fixed quantity. We then focus mostly on the fundamental one. We provide a general definition for the minimal, i.e., unavoidable fundamental energy consumption in creating a maximally resourceful state expressed in units of Jule per rbit (energy invested while generating a unit of resource). We then provide an upper bound on this quantity in case of generated quantum entanglement encoded as polarization on photons, based on the original BBPSSW quantum entanglement distillation protocol.
We further derive a lower bound on the fundamental energy cost of the standards procedure of entanglement generation (taking maximally entangled states as input to the channels). Hence, under the current design, we provide a quantitative estimate (a lower bound) of the inevitable energy consumption in future quantum networks.

SpeedTalk Session II – 30/01/2025

A decompositional framework for process theories in spacetime

Matthias Salzger
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
There has been a recent surge in interest in quantum foundations coming from incorporating ideas from general relativity and quantum gravity. In particular, the field of indefinite causal order has emerged and is now an important research topic in its own right. Many of the tools that we use in quantum foundations and information, are, however, totally agnostic as to the underlying spacetime in which the quantum systems live. To give a practical example, whenever we draw a quantum circuit we are not taking into account the connectivity of the physical qubits which will realize this circuit. In this work, we aim to address this limitation. In particular, we show how to extend the formalism of process theories (a framework to study both quantum and post-quantum theories) to incorporate a background causal structure arising from a fixed spacetime. We discuss when processes are embeddable in

spacetime under certain constraints. To this end, we introduce the concept of implementations of a process, which are decompositions of the process. A process is then embeddable if one of its implementations can be embedded in such a way that all the processes are localized and all wires follow time-like paths. The set of all implementations of a process is a rather unwieldy object but we show that there exists a subset with useful properties which tells us everything we need to know about the remaining implementations and the embeddability of a process. We call this subset the set of minimal representatives. Future directions include defining and analysing the compositional structure of the framework more rigorously, extending the framework to indefinite causal structures, studying exotic causal influence, and using the minimal representatives to probe the decompositional structure of quantum theory and beyond.

Optimization of experimental quantum randomness expansion

Piotr Mironowicz
Stockholm University, Sweden

Abstract:
Quantum technologies provide many applications for information processing tasks that are impossible to realize within classical physics. These capabilities include such fundamental resources as generating secure, i.e. private and unpredictable random values. Yet, the problem of quantifying the amount of generated randomness is still not fully solved. This work presents a comprehensive analysis of the design and performance optimization of a Quantum Random Number Generator (QRNG) based on Bell inequality violations. We investigate key protocol parameters, including the smoothing parameter (ϵ_s), test round probability (γ), and switching delays, and their effects on the generation rate and quality of randomness. We identify optimal ranges for γ and p_Ω (the protocol's non-aborting probability) to balance the trade-off between randomness consumption and net randomness generation. Additionally, we explore the impact of switching delays on the system's performance, providing strategies to mitigate these effects. Our results indicate substantial developments in QRNG implementations and offer higher randomness expansion rates. The work provides practical guidelines for the efficient and secure design of QRNG systems and other cryptographic protocols.

https://arxiv.org/abs/2411.04934

Fourier mode decomposition as a method for solving non-equilibrium steady states of fractured atomic loops for atomic microwave receiver

Bartosz Kasza
Centre for Quantum Optical Technologies (QOT), Centre of New Technologies, University of Warsaw

Abstract:
Multi-level atoms, e.g. excited to Rydberg states, present many unique opportunities, but present several challenges for numerical treatment of their interaction with multiple laser fields. In hot-atom systems this is further aggravated by the necessity to include Doppler broadening. Further challenges arise if the system is time-dependent, as the system then doesn’t have a strict steady-state solution. Our study presents a numerically efficient approach to solving non-equilibrium steady states, focusing on fractured atomic loops, as exemplified by Rydberg-atom microwave sensing protocols. By manipulating terms within the master equation and applying Fourier expansion of Floquet-Lindblad modes, we uncover new insights into the control and coherence of atomic states under periodic driving, resulting from fracture. The results are particularly relevant for superheterodyne Rydberg sensors, where the main question is the efficient transfer of modulation from a weak microwave signal field to light. These findings enhance our understanding of quantum dynamics in Floquet systems and offer potential applications in modelling quantum communication, sensing and transduction protocols.

https://arxiv.org/abs/2412.07632

Robustness of chaotic-light correlation imaging against turbulence

Giovanni Scala
Istituto Nazionale di Fisica Nucleare, Italy

Abstract:
We consider an imaging scheme, inspired by microscopy, in which both correlation imaging and direct intensity imaging can be performed simultaneously, to investigate the effects of strong turbulence on the two different images. The theoretical comparison between direct and correlation imaging in the presence of strong turbulence unambiguously reveals an advantage of the latter. Remarkably, this advantage, quantified by analyzing the visibility of periodic sample patterns, is more striking when the presence of turbulence becomes the dominant factor in determining the image resolution.

https://link.springer.com/article/10.1140/epjp/s13360-024-05769-w

Experimental demonstration of the equivalence of entropic uncertainty with wave-particle duality

Pedro Dieguez
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
Wave-particle duality is one of the most notable and counterintuitive features of quantum mechanics, illustrating that two incompatible observables cannot be measured simultaneously with arbitrary precision. In this work, we experimentally demonstrate the equivalence of wave-particle duality and entropic uncertainty relations using orbital angular momentum (OAM) states of light. Our experiment uses an innovative and reconfigurable platform composed of few-mode optical fibers and photonic lanterns, showcasing the versatility of this technology for quantum information processing. Our results provide fundamental insights into the complementarity principle from an informational perspective, with implications for the broader field of quantum technologies.

https://arxiv.org/abs/2407.03797

All-optical receiving of weak microwave fields in room-temperature Rydberg atoms

Sebastian Borówka
Centre for Quantum Optical Technologies (QOT), Centre of New Technologies, University of Warsaw

Abstract:
The sensing of microwave fields in wide range of bands is a widely researched topic in the field of high frequency detection techniques. Atomic media, in particular Rydberg atoms are especially promising, as they can be tuned to various bands with a single device, pointing to immediate miniaturization and integrated solutions with their potentially all-optical interfaces. However, in the state-of-the art methods the best sensitivity to incoming fields is achieved when an additional local oscillator field is used to bias the atoms to the optimal detection working point. Here we show that the same merit can be achieved using a pair of additional optical fields, retaining the all-optical interface, which presents better prospects for weakly-disturbing, stealthy detection.

https://arxiv.org/abs/2403.05310

Interactions-enhanced microwave sensing with Rydberg atoms

Mateusz Mazelnik
Centre for Quantum Optical Technologies (QOT), Centre of New Technologies, University of Warsaw

Abstract:
We demonstrate a quantum-enhanced protocol for sensing electromagnetic fields using cold Rydberg atoms. The protocol employs collective Rydberg excitations in a cold atomic cloud to estimate the Rabi rotation angle between two Rydberg states induced by microwave radiation. The sensitivity is enhanced by exploiting interactions between the two Rydberg states, which erase contributions in the Fock representation of the final state that would otherwise contribute to noise in the presence of losses. This error-correction mechanism, though introducing additional losses, allows for improved extraction of information from the lossy detection channel, thereby boosting the precision in estimating the rotation angle and, consequently, the electric field amplitude.

Rydberg atoms in space

Michał Parniak
Centre for Quantum Optical Technologies (QOT), Centre of New Technologies, University of Warsaw

Abstract:
I will discuss a new project undertaken by out team where we will construct a prototype breadboard for the European Space Agency, in order to demonstrate the feasibility of Rydberg-atom based microwave sensors in space industry applications. The project represents the first commercial enterprise of our experimental team, stemming from the extraordinary performance of the new microwave and atom-based quantum sensing method developed in our lab.

SpeedTalk Session III – 30/01/2025

Activation of post-quantumness in bipartite generalised EPR scenarios

Beata Zjawin
International Centre for Theory of Quantum Technologies (ICTQT), University of Gdańsk

Abstract:
In a standard bipartite Einstein-Podolsky-Rosen (EPR) scenario, Alice and Bob share a system prepared in an entangled state and Alice performs local measurements. One possible generalisation of this set-up is to allow Bob to also locally process his subsystem. Then, correlations generated in such generalised EPR scenarios are examples of non-signalling bipartite resources, called assemblages, that can exhibit post-quantum behavior, i.e., cannot be generated using solely quantum systems. There exist assemblages that, despite being post-quantum resources, can only generate quantum correlations in bipartite Bell-type scenarios. Here, we present a protocol for activation of post-quantumness in bipartite generalised EPR scenarios such as the so-called Bob-with-input, measurement-device-independent, and channel EPR scenarios. By designing a protocol that involves distributing the assemblages in a larger network, we derive tailored Bell inequalities which can be violated beyond their quantum bound in this new set-up. Our results show that in all of the above generalised scenarios, the post-quantumness of the assemblages can be witnessed at the level of correlations they produce.

https://arxiv.org/abs/2406.10697

Characterization of EHF band emitters using Rydberg atoms and metamaterials

Wiktor Krokosz
Centre for Quantum Optical Technologies (QOT), Centre of New Technologies, University of Warsaw

Abstract:
Rydberg atomic sensors offer highly sensitive and traceable RF field measurements across diverse frequency ranges. In this work, we present the detection of electric field amplitudes at 131 GHz within the extremely high frequency (EHF) band. Our approach employs beam propagation with photonic waveplates to precisely control direction and polarization at the detector, enhancing sensitivity through collinear propagation and circular polarization. To demonstrate real-world applicability, we perform measurements on EHF signals emitted by an on-chip automotive radar designed for vital sign monitoring. This work highlights the integration of Rydberg atomic media with photonic metamaterials, underscoring their potential for next-generation automotive and sensing technologies.

https://arxiv.org/abs/2406.04021

Scalable noisy quantum circuits for biased-noise qubits

Moein Naseri
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Abstract:
In this work, we consider biased-noise qubits affected only by bit-flip errors, which is motivated by existing systems of stabilized cat qubits. This property allows us to design a class of noisy Hadamard-tests involving entangling and certain non-Clifford gates, which can be conducted reliably with only a polynomial overhead in algorithm repetitions. On the flip side we also found classical algorithms able to efficiently simulate both the noisy and noiseless versions of our specific variants of Hadamard test. We propose to use these algorithms as a simple benchmark of the biasness of the noise at the scale of large circuits. The bias being checked on a full computational task, it makes our benchmark sensitive to crosstalk or time-correlated errors, which are usually invisible from individual gate tomography. For realistic noise models, phase-flip will not be negligible, but in the Pauli-Twirling approximation, we show that our benchmark could check the correctness of circuits containing up to 10^6 gates, several orders of magnitudes larger than circuits not exploiting a noise-bias. Our benchmark is applicable for an arbitrary noise-bias, beyond Pauli models.

https://arxiv.org/abs/2305.02045

Superresolution in systems evolving under Brownian motion utilizing spatial mode demultiplexing

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Abstract:
The development of superresolution techniques, i.e., allowing for efficient resolution below the Rayleigh limit, became one of the important branches in contemporary optics and metrology. Recent findings show that perfect spatial mode demultiplexing (SPADE) into Hermite-Gauss modes followed by photon counting enables one to reach the quantum limit of precision in the task of estimation of separation between two weak stationary sources in the sub-Rayleigh regime. To check the limitations of the method, various imperfections such as misalignment or crosstalk between the modes were considered.
Possible applications of the method in microscopy call for the adaptive measurement scheme, as the position of the measured system can evolve in time, causing non-negligible misalignment. In this paper, we examine the impact of Brownian motion of the center of the system of two weak incoherent sources of arbitrary relative brightness on

adaptive SPADE measurement precision limits. As a result, we find that Rayleigh's curse is present in such a scenario; however, SPADE measurement can outperform perfect direct imaging. What is more, a suitable adjustment of the measurement time between alignments allows measurement with near-optimal precision.

https://arxiv.org/abs/2407.13723

Optical beating frequency measurement with PLL

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Abstract:
An easy and precise method for reading frequency of scanning lasers is using a phase-locked loop (PLL) on a signal of beating with another, more stable laser. This approach with digital signal analysis is easily deployable, modifiable, works in a wide range of frequencies and permits error control.

Troubleshooting a weak vacuum optical cavity lock: A student's guide

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Abstract:
Ever since the advent of the maser in 1954, and quickly after, the laser in 1960, the need to stabilize it for experiments has existed. Methods to do so struggled when the laser would have intensity instabilities, so the Pound-Drever-Hall (PDH) technique was developed. This used an optical cavity more stable than the laser source, or vice versa if desired, stabilizing it with regards to frequency of laser emission regardless of intensity. Here, the technique was implemented to pass a stable laser to an optical cavity to an unstable laser source. Typical problems and solutions were documented to provide a simple guide to the style of cavity design and assembly.

SpeedTalk Session IV – 31/01/2025

Study of Quantum Systems with Physics-Informed Neural Networks

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Abstract:
The use of deep learning in physical sciences has recently boosted the ability of researchers to tackle physical systems where little or no analytical insight is available. Recently, the Physics-Informed Neural Networks (PINNs) have been introduced as one of the most promising tools to solve systems of differential equations guided by some physically grounded constraints. In the quantum realm, such an approach paves the way for a novel approach to solving the Schroedinger equation for non-integrable systems. Following an unsupervised learning approach, we apply the PINNs to the anharmonic oscillator in which an interaction term proportional to the fourth power of the position coordinate is present. We compute the eigenenergies and the corresponding eigenfunctions while varying the weight of the quartic interaction. We bridge our solutions to the regime where both the perturbative and the strong coupling theory work, including the pure quartic oscillator. We investigate systems with real and imaginary frequency, laying the foundation for novel numerical methods to tackle problems emerging in quantum field theory.

https://arxiv.org/abs/2407.20669

Relativistically invariant encoding of quantum information revisited

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Abstract:
In this work, we provide a detailed analysis of the issue of encoding of quantum information which is invariant with respect to arbitrary Lorentz transformations. We significantly extend already known results and provide compliments where necessary. In particular, we introduce novel schemes for invariant encoding which utilize so-called pair-wise helicity -- a physical parameter characterizing pairs of electric-magnetic charges. We also introduce new schemes for ordinary massive and massless particles based on states with fixed total momentum, in contrast to all protocols already proposed, which assumed equal momenta of all the particles involved in the encoding scheme. Moreover, we provide a systematic discussion of already existing protocols and show directly that they are invariant with respect to Lorentz transformations drawn according to any distribution, a fact which was not manifestly shown in previous works.

https://arxiv.org/abs/2401.01712

Device-independent Shannon entropy certification

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Abstract:
Using Bell inequalities, a user or vendor of a quantum random number generation hardware can certify that the values provided by an untrusted device are truly random. In this paper, we analyze the feasibility of such verification for 2-bit QRNG using a selection of Bell inequalities, for Shannon entropy as the measure of randomness. We present that the usability of various Bell inequalities differs depending on the presence of noise. Moreover, we present the difference of certification for Shannon compared to min-entropy.

Geometric monotones of violations of quantum realism

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Abstract:
Quantum realism, as introduced by Bilobran and Angelo [EPL 112, 40005 (2015)], states that projective measurements in quantum systems establish the reality of physical properties, even in the absence of a revealed outcome. This framework provides a nuanced perspective on the distinction between classical and quantum notions of realism, emphasizing the contextuality and complementarity inherent to quantum systems. While prior works have quantified violations of quantum realism (VQR) using measures based on entropic distances, here we extend the theoretical framework to geometric distances. Building on an informational approach, we derive geometric monotones of VQR using trace distance, Hilbert-Schmidt distance, Schatten p-distances, Bures, and Hellinger distances. We identify Bures and Hellinger distances as uniquely satisfying all minimal criteria for a bona fide VQR monotone. Remarkably, these distances can be expressed in terms of symmetric R\'enyi and Sandwiched R\'enyi divergences, aligning geometric and entropic approaches. Our findings suggest that the realism-information relation implies a deep connection between geometric and entropic frameworks, with only those geometric distances expressible as entropic quantities qualifying as valid monotones of VQR. This work highlights the theoretical and practical advantages of geometric distances, particularly in contexts where computational simplicity or symmetry is important.

https://arxiv.org/abs/2412.11633

Noncontextual ontological models of operational probabilistic theories

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Abstract:
The study of ontological models and generalized noncontextuality has recently been reformulated using the framework of generalized probabilistic theories (GPTs). A related framework, operational probabilistic theories (OPTs), raises the question of how to adapt ontological models and generalized noncontextuality within this framework. A key feature of OPTs is their explicit specification of "tests," which define how collections of transformations—analogous to valid quantum instruments—are organized. This test structure might appear to allow contextual representations, as equivalence classes can belong to multiple tests, with the test identity potentially serving as a contextual variable. Somewhat surprisingly, we show that this is not the case: representations of quotiented OPTs are fully determined by their action on transformations and extend naturally to tests. that provides a basis for defining contextuality in ontological models of (unquotiented) OPTs in terms of whether they factorize through the corresponding quotiented OPT.

Operational Analysis of Superluminal Observers

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Abstract:
The theory of relativity is generally assumed to provide us with a speed limit for all interactions. Nevertheless, over the years, this assumption has been frequently questioned and the idea of breaking this speed limit has popped up from time to time in an attempt to explain various phenomena. Most recently, Ekert and Dragan have argued that in a world with superluminal observers local determinism is impossible. In this way, the inherent randomness of quantum theory could be not just reconciled with the theory of relativity but the former can be understood as a consequence of the latter. In this work we develop operational tools for accommodating superluminal observers in an extension of the framework of Quantum Reference frames. We analyze several physical principles and achievable probabilities in a world with superluminal observers and discuss why we possibly should/ should not observe superluminal observers as the connection between relativity and quantum theory.

Charging Quantum Batteries by an Incoherent Source

Paweł Mazurek
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Abstract:
The transfer of energy from a coherent source to a quantum battery is of significant technological importance. However, perhaps even more crucial is the ability to transfer energy from an incoherent source to a quantum battery and store it in a coherent form. In this study, we propose a novel approach to accomplish this task. Our method involves utilizing indistinguishable two-level fermions as the fundamental units of the quantum battery, collectively interacting with a shared reservoir. We demonstrate that non-zero coherent energy, specified as ergotropy, can indeed be transferred to the battery. Furthermore, we observe that, by increasing the number of cells in the battery, near-perfect ergotropy extraction of the battery occurs. Finally, our analysis reveals that the charging power of the battery experiences an enhancement with an increase in the temperature of the reservoir.

A Geometrical Relation Between Noncontextuality and Quantum State Discrimination

Felipe Barretto
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Abstract:
Quantum state discrimination is a widely used tool in both the development of quantum technologies and the study of quantum foundations. In this presentation, we explore a geometrical connection between noncontextuality and quantum state discrimination. We show that if the states in a discrimination task are not affinely independent, the error probability for the task must exceed that of a family of computationally simpler tasks. Furthermore, we demonstrate that the absence of a noncontextual model guarantees affine dependence. This approach hints at an algorithmic framework for establishing upper bounds on guessing probabilities and offers insights into the interplay between noncontextuality and quantum information processing.

SpeedTalk Session V – 31/01/2025

On the structure of the cone of k-positive maps

Marcin Marciniak
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Abstract:
We present a general characterization of k-positivity for a positive map in terms of the estimation of the Ky Fan norm of the matrix constructed from the Kraus operators of the associated completely positive map. Combining this with the result given by Takasaki and Tomiyama we construct a family of positive maps between matrix algebras of different dimensions depending on a parameter. The estimate bounds on the parameter to obtain the k-positivity are better than those derived from the spectral conditions considered by Chruściński and Kossakowski. We further look with special attention at the case where we give the precise bound for the regions of decomposability.

https://arxiv.org/abs/2104.14058

The composition rule for quantum systems is not the only possible one

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Abstract:
Quantum theory provides a significant example of two intermingling hallmarks of science: the ability to consistently combine physical systems and study them compositely; and the power to extract predictions in the form of correlations. A striking consequence of this facet is the violation of local realism, which has been experimentally demonstrated via so-called Bell tests. The prediction of this phenomenon originates as quantum systems are prescribed to combine according to the composition postulate, i.e. the tensor-product rule. This rule has also an operationally sound formulation -- rather than just a purely mathematical one -- given in terms of discriminability of states via local measurements. Yet, both the theoretical and the empirical status of such postulate has been constantly challenged over the decades: is it possible to deduce it from the remaining postulates? Here, we solve this long-standing problem by answering in the negative. We formulate a family of operational theories that are solely distinguished from quantum theory by their system-composition rule, while, at the same time, they cannot be told apart by Bell-like experiments. Quantum theory is thus established to genuinely embody more content than quantum correlations. As a result, foundational programs only based on single-system principles, or on bare correlations, are operationally incomplete. On the experimental side,

ascertaining the independence of postulates is a fundamental step to adjudicate between quantum theory and alternative physical theories: hence, the composition postulate deserves to be experimentally scrutinised independently of the other features of quantum theory.

https://arxiv.org/abs/2411.15964

Oracle problems as communication tasks and optimization of quantum algorithms

Amit Te'eni
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Abstract:
Quantum query complexity mainly studies the number of queries needed to learn some property of a black box with high probability. A closely related question is how well an algorithm can succeed with this learning task using only a fixed number of queries. In this work, we propose measuring an algorithm's performance using the mutual information between the output and the actual value. A key observation is that if an algorithm is only allowed to make a single query and the goal is to optimize this mutual information, then we obtain a task which is similar to a basic task of quantum communication, where one attempts to maximize the mutual information of the sender and receiver. We make this analogy precise by formally considering the oracle as a separate subsystem, whose state records the unknown oracle identity. The oracle query prepares a state, which is then measured; and the target property of the oracle plays the role of a message that should be deduced from the measurement outcome. Thus we obtain a link between the optimal single-query algorithm and minimization of the extent of quantum correlations between the oracle and the computer subsystems. We also find a lower bound on this mutual information, which is related to quantum coherence. These results extend to multiple-query non-adaptive algorithms. As a result, we gain insight into the task of finding the optimal non-adaptive algorithm that uses at most a fixed number of queries, for any oracle problem.

https://arxiv.org/abs/2409.15549

Randomness-free Detection of Non-projective Measurements: Qubits & beyond

Sumit Rout
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Abstract:
Non-projective measurements play a crucial role in various information-processing protocols. In this work, we propose an operational task to identify measurements that are neither projective nor classical post-processing of data obtained from projective measurements. Our setup involves space-like separated parties with access to a shared state with bounded local dimensions. Specifically, in the case of qubits, we focus on a bipartite scenario with different sets of target correlations. While some of these correlations can be obtained through non-projective measurements on a shared two-qubit state, it is impossible to generate these correlations using projective simulable measurements on bipartite qubit states, or equivalently, by using one bit of shared randomness and local post-processing. For certain target correlations, we show that detecting qubit non-projective measurements is robust under arbitrary depolarizing noise, except in the limiting case. For qutrits, we extend this task and demonstrate that some correlations achievable via local non-projective measurements cannot be reproduced by both parties performing the same qutrit projective simulable measurements on their pre-shared state. We provide numerical evidence for the robustness of this scheme under arbitrary depolarising noise. For a more generic consideration (bipartite and tripartite scenario), we provide numerical evidence for a projective-simulable bound on the reward function for our task. We also show a violation of this bound by using qutrit POVMs. From a foundational perspective, we extend the notion of non-projective measurements to general probabilistic theories (GPTs) and use a randomness-free test to demonstrate that a class of GPTs, called square-bits or box-world are unphysical.

https://arxiv.org/abs/2412.00213

Testing nonclassicality in a photonic processor

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Abstract:
We leverage a linear program developed to check the existence of a simplex embedding for a set of states and effects of a generalised probabilistic theory, showing that a subset of data from a single-photon experiment in a universal photonic processor can provide a proof of generalised contextuality.

Keldysh field theory for density matrix formalism with applications in quantum information processing

Luis Cort Barrada
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Abstract:
In this work we develop a theoretical Open Quantum Systems methodology based on the Keldysh field theory formalism, capable of addressing moderate system-bath interactions, non-Markovian memory effects, and external time-dependent fields.

Quantum state tomography of pure three-qubit states from its parts

Akshata Shenoy
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Abstract:
We present a scheme for reconstructing an arbitrary three-qubit state by employing 17 measurements in contrast to 64 Pauli measurements required for a full quantum state tomography. Additionally, a pure three-qubit state could be reconstructed from its two-qubit reduced density matrices. We employ a tomographic scheme involving 7 measurements for two-qubit reduced states of a pure three-qubit state. Experimental implementation of both the schemes on a 127-qubit IBM open access quantum processor is demonstrated for reconstruction of the three-qubit W state. It is seen that the fidelity of the three-qubit W state reconstructed from quantum tomography of its reduced two-qubit states is considerably better as compared to employing the three-qubit tomographic construction itself.

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3. S. Dogra, A. A. Melnikov, G. S. Paraoanu, "Quantum simulation of parity time symmetry breaking with a superconducting quantum processor," Comm. Phys. 4, 26-1–8 (2021).

Quantum machine learning models for cancer detection

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Abstract:
Cancer is the second biggest cause of human deaths. Early diagnosis is a key element of therapy. Liquid biopsy are excellent samples for cancer detection as they are minimally invasive and cost effective. In recent years, there has been a growing interest in machine learning techniques and models. Intersection between machine learning and

quantum computation promises great possibilities. During my presentation I will show the work already made by prof. Anna Supernat group from Gdańsk University of Medicine. I will present the Support Vector Machine method in its classical version and in the version enriched by quantum computation. I will compare both approaches and present applications of Quantum Support Vector Machine in biomedical research.

Against (unitary) interpretation (of quantum mechanics): removing the metaphysical load

Marek Żukowski

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Abstract:

Physics is a science. Thus a statement can be treated as its “law” only if it agrees with our experience of the World/Nature (this includes our experiments). Statements which are fundamentally untestable are hypotheses which belong to metaphysics. Such are all interpretations of quantum mechanics, which attribute to its mathematical tools meanings that are beyond experimentally observable events, while not affecting quantum predictions of these events. We show that “unitary quantum mechanics”, which according to its followers leads to some interesting paradoxes, is an interpretation of quantum mechanics, based on hypotheses that are untestable. The (operational) quantum mechanics, which is the one tested in every quantum experiment is free of these paradoxes. The root of “unitary” vs. operational discrepancy is that the latter treats the measurement process as irreversible, and in the different answers to the question of what is described by the state vector. The clearest manifestation of this is the insistence of the supporters of “unitary quantum mechanics” that measurements can be “in principle undone”. “Unitarists” also try to avoid the postmeasurement state vector collapse at any cost, including no attempt to describe it, but still accept the Born rule as a calculational tool. Modern understanding of the collapse postulate is via the decoherence theory of measurement, which allowed to replace Copenhagenish intuitions about classical treatment of the laboratory apparatuses by analysis showing emergence of the apparatuses' classical-like behaviour via decoherence due to the interaction with zillions of degrees of freedom describing the atomic/quantum structure of the devices and their environment. This in turn can be shown to lead to the impossibility of reversing the apparatus-system interaction, which happens during any laboratory measurement process. The hypothesis that unitary interaction between system, pointer variable, detectors and environment leading to a measurement can be “in principle undone” is untestable, as it is impossible to build a quantum simulator showing the possibility of controlling such a process for so complex systems. This is not an in-principle-impossibility, but an absolute impossibility, as the environment is by definition uncontrollable. {\em Ipso facto}, the hypothesis of “in principle possibility of undoing measurements” belongs to metaphysics, as it is untestable. In the case of predictions of factual events in the laboratories the “unitary” quantum mechanics agrees with the operational one. It shares this property with all interpretations of quantum mechanics which do not affect its predictions. Metaphysics begins when one requests that quantum mechanics should be more than a mathematically formulated theory which predicts future observable events of a certain class basing on events observed earlier (of the same class).

https://arxiv.org/abs/2409.17061