MON 7: Foundational / Mathematical Aspects – Quantum Measurement

Time: Monday 14:15–16:15 Location: ZHG008

MON 7.1 Mon 14:15 ZHG008

Weak values as stereographic projections — Lorena Ballesteros Ferraz[1,3], Dominique L. Lambert[2], and •Yves Caudano[3] — [1]Present address: Lab. de Physique Théorique et Modélisation, CNRS Unité 8089, CY Cergy Paris Université, France — [2]SPS department, esphin and naXys, University of Namur, Belgium — [3]Physics department, naXys and NISM, University of Namur, Belgium

Quantum weak measurements generate a lot of fundamental and practical interest, as weakly perturbing probes or means of amplifying small effects. In a pre- and post-selected weak measurement, the experimental deflection of the measuring device depends on the real part or on the imaginary part of the weak value, a complex number. However, weak values also possess a polar representation. We have connected the argument of weak values in N-level systems to a geometric phase [1] related to a geodesic triangle in the quantum state manifold. Building on results developed for open quantum systems [2], we now demonstrate that arbitrary weak values can be interpreted as a stereographic projection of the post-selected state. This offers a comprehensive geometric interpretation of the weak value's modulus and argument, enabling its visualisation jointly with the associated quantum states. Then, the geometric phase appears as both a complex-plane angle and a solid angle on the Bloch sphere, effectively mapping the weak value onto an effective two-level system.

[1] L. B. Ferraz, D. L. Lambert, and Y. Caudano, Quantum Sci. Technol. 7 (2022) 045028. [2] L. B. Ferraz, J. Martin, and Y. Caudano, Quantum Sci. Technol. 9 (2024) 035029.

MON 7.2 Mon 14:30 ZHG008

Present status and future challenges of non-interferometric tests of collapse models — •Matteo Carlesso — University of Trieste, Strada Costiera 11, 34151 Trieste — Istituto Nazionale di Fisica Nucleare, Trieste Section, Via Valerio 2, 34127 Trieste, Italy

The superposition principle is the cornerstone of quantum mechanics, leading to a variety of genuinely quantum effects. Whether the principle applies also to macroscopic systems or, instead, there is a progressive breakdown when moving to larger scales is a fundamental and still open question. Spontaneous wavefunction collapse models predict the latter option, thus questioning the universality of quantum mechanics. Technological advances allow to increasingly challenge collapse models and the quantum superposition principle, with a variety of different experiments. Among them, non-interferometric experiments proved to be the most effective in testing these models. We provide an overview of such experiments, including cold atoms, optomechanical systems, X-ray detection, bulk heating and comparisons with cosmological observations. We also discuss avenues for future dedicated experiments, which aim at further testing collapse models and the validity of quantum mechanics.

MON 7.3 Mon 14:45 ZHG008

The role of redundant correlated records in the emergence of Objective Classical Reality — •VIshal Johnson[1,2], Ashmeet Singh[3], and Torsten Ensslin[1,2] — [1]Max Planck Institute for Astrophysics, Garching, Germany — [2]Ludwig Maximilians University, Munich, Germany — [3]Whitman College, Walla Walla, USA

Quantum measurement inevitably involves a physical system, the observer, in which the result of the measurement procedure is stored. Therefore, in the context of unitary (reversible) quantum mechanics, one has to include the observer as a physical system operating within the limits of quantum mechanics. We argue that a physical quantity (correlation) is a resource used up in each quantum measurement. We put constraints on the nature of environmental/observer states which lead to redundant, classical record formation — correlation can be provided by a GHZ-like state before or after the interaction with the measured system. A network of such measurements establishes a stable objective classical reality — the redundant agreement of several observers on the state of the measured quantum system. We verify our hypotheses by simulating the quantum measurement procedure — observer network states with a high amount of correlation gives rise to high fidelity measurement results.

MON 7.4 Mon 15:00 ZHG008

Ultradecoherence model of the measurement process — •Hai-Chau Nguyen — University of Siegen

It is proposed that measurement devices can be modelled to have an open decoherence dynamics that is faster than any other relevant timescale, which is referred to as the ultradecoherence limit. In this limit, the measurement device always assumes a definite state upto the accuracy set by the fast decoherence timescale. Further, it is shown that the clicking rate of measurement devices can be derived from its underlying parameters, not only for the von Neumann ideal measurement devices but also for photon detectors in equal footing. This study offers a glimpse into the intriguing physics of measurement processes in quantum mechanics, with many aspects open for further investigation.

MON 7.5 Mon 15:15 ZHG008

Quantifying quantum coherence and the deviation from the total probability formula — •Antoine Soulas — IQOQI Vienna, Austria

Quantum coherence is the main resource exploited by quantum computers. Unsurprisingly, over the past few years, there has been a strong interest in the task of finding appropriate measures of coherence. We propose a novel approach which, contrary to the previous ones, relies on foundational/philosophical considerations. It allows to solve two drawbacks of the resource theoretic approach: the lack of physical meaning, and the restriction to one particular basis in which to quantify coherence. In our approach, coherence is understood as the ability for a quantum system's statistics to deviate from the total probability formula.

After motivatng the importance of the total probability formula in quantum foundations, we then propose a new set of axioms that a measure of coherence should satisfy, and show that it defines a class of measures different from the previous proposals. Finally, we prove a general result about the dependence of the l2-coherence norm on the basis of interest, namely that it is well approximated by the square root of the purity in most bases. Such a behaviour (the nearly constant level of coherence in most bases) is actually expected for any measure of coherence, because of the mathematical phenomenon known as "concentration of measure".

MON 7.6 Mon 15:30 ZHG008

Which-way knowledge increase via feed-forward of the interfering particle's phase — •Elisabeth Meusert, Marc-Oliver Pleinert, and Joachim von Zanthier — Friedrich-Alexander Universität, Erlangen, Germany

Complementarity constitutes a central aspect of quantum theory. It manifests itself for example in a two-way interferometer, where the simultaneous observation of an interference pattern and the aquisition of which-way information are limited by an inequality, known as the duality relation.

We investigate which-way information in a double-slit interferometer. We find that, depending on the which-way detector observable chosen, the which-way information can be correlated to the interfering particle's phase at the interferometer screen, leading to a phase-dependent which-way knowledge. In specific cases, this knowledge can locally exceed the limit set by the duality relation. Based on this observation, we propose a delayed choice protocol that aims at maximizing the which-way information locally for each phase after the particle has been read out. This allows us to surpass the duality relation limit on phase-average. We present analytical results as a proof of principle of our protocol as well as numerical outcomes quantifying the amount of achievable which-way knowledge.

MON 7.7 Mon 15:45 ZHG008

The Contextual Heisenberg Microscope — •Jan-Åke Larsson — Linköpings Universitet, Linköping, Sweden

The Heisenberg microscope provides a powerful mental image of the measurement process of quantum mechanics (QM), attempting to explain the uncertainty relation through an uncontrollable back-action from the measurement device. However, Heisenberg's proposed back-action uses features that are not present in the QM description of the world, and according to Bohr not present in the world. Therefore, Bohr argues, the mental image proposed by Heisenberg should be avoided. Later developments by Bell and Kochen-Specker shows that a model that contains the features used for the Heisenberg microscope is in principle possible but must be nonlocal and contextual. In this paper we will re-examine the measurement process within a restriction of QM known as Stabilizer QM, that still exhibits for example Greenberger-Horne-Zeilinger nonlocality and Peres-Mermin contextuality, using a recent extension of stabilizer QM, the Contextual Ontological Model (COM), where the system state gives a complete description of future measurement outcomes reproducing the quantum predictions, including the mentioned phenomena. The resulting contextual Heisenberg microscope back-action can be completely described within COM; the associated randomness originates in the initial state of the pointer system, exactly as in the original description of the Heisenberg microscope. The presence of contextuality, usually seen as prohibiting ontological models, suggests that the contextual Heisenberg microscope picture can be enabled in general QM.

MON 7.8 Mon 16:00 ZHG008

Measuring the speed of quantum particles without a round-trip under non-synchronized quantum clocks — •Tomer Shushi — Ben-Gurion University of the Negev, Beer Sheva, Israel

In this talk, we show that it is possible, in principle, to measure the velocity of particles that travel at the speed of light without assuming a round-trip once we adopt a quantum mechanical description under two boundary conditions to the state of the quantum system followed by the two-state-vector formalism while assuming non-synchronized quantum clocks with unknown time dilation [1]. The weak value of velocity can be measured for a test particle that has a clock that is not synchronized with the clock of the quantum particle. Following the proposed setup, when the weak value of the velocity is known even without knowing the time states of the system, such a weak velocity is the two-way speed of light. We further explore some fundamental implications of the setup. The proposed approach opens a new avenue toward measuring the velocities of quantum particles while overcoming relativistic issues regarding the synchronization of clocks. [1] Shushi, T. (2025). Measuring the speed of quantum particles without a round-trip under non-synchronized quantum clocks. Proceedings of the Royal Society A. 481: 20240708.