# Universal protection of quantum states from decoherence

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Decoherence, i.e. the inevitable coupling of quantum states to their environment, remains a primary obstacle for the widespread diffusion of several quantum technologies. While the Quantum Zeno Effect (QZE) [1,2] is a well-established quantum control method for suppressing decoherence-induced noise, its application typically necessitates prior knowledge of the quantum state to be protected [3-6]. In order to overcome this limitation, here we introduce a new protocol named Quantum State Universal Protection (QSUP), providing state-independent protection for arbitrary quantum states [7]. We experimentally demonstrate QSUP using polarization-encoded single photon qubits in a quantum channel hosting a Mach-Zehnder-like interferometer (MZI), in which controlled decoherence is implemented via birefringence. By spatially separating the qubit polarization components within the MZI arms, we apply frequent QZE-projections on each polarization component to stabilize the state against birefringence-induced decoherence. Our experimental results [7] show near-unity Fidelity and Purity for the QSUP-assisted qubit transmission in several different scenarios, dramatically increasing the robustness and reliability of the transmitted quantum information. Our strategy is universally applicable, since it is independent of the form of decoherence occurring within the quantum channel as well as of the specific quantum state undergoing QSUP, in contrast to state-dependent protection schemes or tailored quantum error-correction codes. As such, it provides a broadly applicable solution for quantum communication, distributed quantum sensing, and quantum computation.

[1] B. Misra and E. C. G. Sudarshan, The zeno's paradox in quantum theory. J. of Math. Phys. 18, 756 (1977).

[2] W. M. Itano, D. J. Heinzen, J. J. Bollinger, and D. J. Wineland, Quantum zeno effect. Phys. Rev. A 41, 2295 (1990).

[3] F. Piacentini et al., Determining the quantum expectation value by measuring a single photon. Nat. Phys. 13, 1191 (2017).

[4] E. Rebufello et al., Protective Measurement - A New Quantum Measurement Paradigm: Detailed Description of the First Realization. Appl. Sci. 11, 4260 (2021).

[5] S. Virzì et al., Quantum zeno and anti-zeno probes of noise correlations in photon polarization. Phys. Rev. Lett. 129, 030401 (2022).

[6] S. Virzì et al., Sensing microscopic noise events by frequent quantum measurements. Phys. Rev. Appl. 21, 034014 (2024).

[7] F. Atzori et al., Universal Protection of Quantum States from Decoherence. arXiv:2602.18327 (2026).