Entanglement Dynamics of Locally Monitored Free Fermions

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Abstract: Monitored quantum many-body systems reveal intricate entanglement dynamics from alternating unitary evolution and measurements. This study shows how local measurements in free fermions generate volume-law entanglement entropy and super-Poissonian waiting-time statistics of quantum jumps.

In the last decades, out-of-equilibrium quantum many-body systems have garnered significant interest from the scientific community. Within this contest two typical scenarios have emerged: quenches in closed systems and open systems dynamics, usually described by a Lindblad master equation. Here, we present new findings within a framework that lies between these two scenarios i.e. monitored systems.

The standard approach for studying this out-of-equilibrium phenomenon involves the interplay between unitary dynamics, governed by a many-body Hamiltonian or random circuit, and a finite density of local projective measurements. Alternative approaches, such as weak-measurement protocols, incorporate the unraveling of Lindblad evolution, where monitoring is applied stochastically to each lattice site. Recently, quantum jumps and their associated measurements have attracted renewed attention in the context of open quantum many-body systems and their measurement-induced phase transitions [1-3]. This research focuses on the entanglement properties of quantum many-body trajectories and their dependence on the interplay between unitary evolution and measurements. Across these models, measurements drive an entanglement transition, from a volume-law scaling of entanglement (or sub-volume scaling in non-interacting systems) to an area-law regime, where the quantum Zeno effect effectively freezes the system.

We explore the role of monitored dynamics and quantum jumps in a minimal model, where monitoring is applied locally to a single site within an otherwise free fermionic chain [4]. Local perturbations in quantum many-body systems, such as quantum impurities, are known to induce significant effects, such as the orthogonality catastrophe. Here, we show that local non-unitary monitoring produces a surprising growth in entanglement entropy, which saturates at an extensive value scaling with subsystem size, as shown if panel (a) of Fig. 1. This behavior sharply contrasts with both the purely unitary case and the fully postselected no-click limit. Our results highlight the critical role of quantum jumps in generating entanglement.

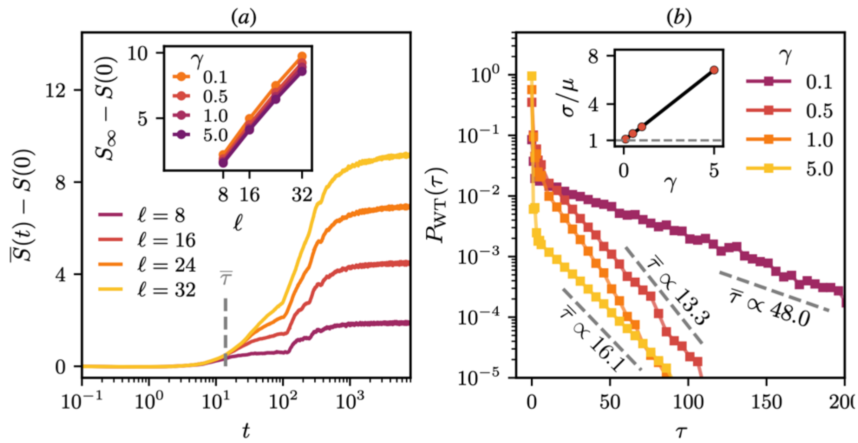

Fig. 1 Panel (a) displays the entanglement entropy as a function of time, with the inset illustrating its scaling with system size. Panel (b) presents the waiting-time distribution of quantum jumps.

We attribute the extensive entanglement to the statistics of quantum jumps, which exhibit periods of bunching interspersed with prolonged dark intervals, similar to the resonance fluorescence of a driven atom. As shown in panel (b) of Fig. 1, the waiting-time distribution of the jumps displays a super-Poissonian nature. These dark periods play a crucial role in enabling extensive entanglement growth. Additionally, as monitoring extends to more sites, entanglement decreases and eventually transitions to the area-law regime, as expected for systems where all lattice sites are monitored.

References

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