Measurement-Induced Transitions in Collective Systems without Postselection

G. Passarelli[1]

1. Università di Napoli Federico II, Dipartimento di Fisica "E. Pancini", Complesso Universitario di Monte Sant'Angelo, via Cinthia, 80126 Napoli, Italia

Abstract: We investigate measurement-induced phase transitions in a permutationally invariant ensemble of monitored two-level atoms, highlighting subextensive entanglement scaling, bistability effects, and the potential to mitigate post-selection challenges in collective quantum systems.

A key challenge in studying measurement-induced phase transitions is overcoming the post-selection barrier, where the probability of reproducing specific measurement sequences decreases exponentially with system size, creating significant obstacles for experimental implementation. Nonetheless, certain systems, particularly those with permutational symmetry and infinite-range Liouvillians, can mitigate this issue under specific conditions.

We investigate the dynamics of a permutationally invariant ensemble of two-level atoms continuously monitored while driven by a laser field of frequency ω_0 and subject to collective decay at a rate κ (see Fig. 1). The quantum trajectories of this system display behaviors that strongly depend on the monitoring protocol, deviating substantially from the predictions of the average density matrix. By adjusting the strength of the external drive, we identify a measurement-induced phase transition separating two phases with subextensive scaling of entanglement entropy relative to system size. Interestingly, the critical point of this transition coincides with the superradiance threshold in trajectory-averaged dynamics, and the entanglement saturation time scales rapidly with system size across the phase diagram. This rapid scaling directly affects the feasibility of post-selection by influencing the computational effort required to reproduce specific trajectories [1].

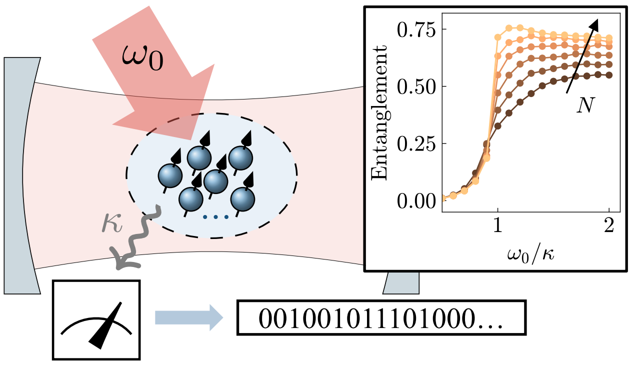

Fig. 1 Collective ensemble of two-level atoms in a cavity. The reconstruction of a quantum trajectory from the sequence of detector clicks can be done efficiently, allowing the experimental probe of measurement-induced entanglement transitions with low post-selection effort.

However, this behavior is not universal to all collective models. In certain permutationally invariant systems, bistability regions can delay entanglement saturation, complicating efforts to overcome the post-selection barrier. Thus, the post-selection challenge is intricately tied to the specific dynamical properties of the system [2].

Our results underscore the potential of permutationally invariant monitored systems as a promising framework for exploring complex quantum dynamics, providing insights into measurement-induced phase transitions and strategies to address post-selection challenges.

References

[1] G. Passarelli, X. Turkeshi, A. Russomanno, P. Lucignano, M. Schirò, R. Fazio, "Many-body dynamics in monitored atomic gases without postselection barrier", Phys. Rev. Lett. **132**, 163401 (2024)

[2] A. Delmonte, Z. Li, G. Passarelli, E. Y. Song, D. Barberena, A. M. Rey, R. Fazio, "Measurement-induced phase transitions in monitored infinite-range interacting systems", arXiv:2410.05394 (2024)