

M2 internship proposal

Steering quantum states through measurements and feedback

Context:

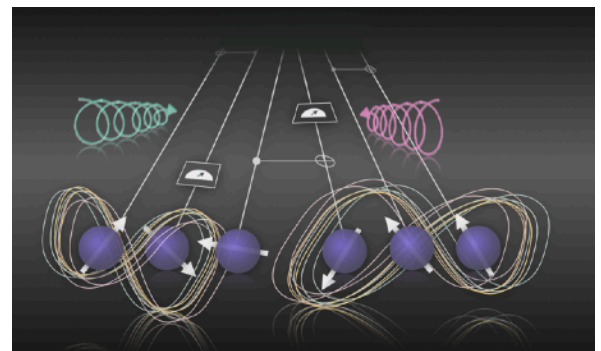
The saying "a watched kettle never boils" finds a precise realization in quantum mechanics. This is because repeated measurements do not simply reveal the dynamics of a quantum system, but can fundamentally alter its evolution. In the case of a single spin the repeated measurement can suppress its unitary evolution, effectively freezing it in its initial state. This phenomenon is known as the *quantum Zeno effect*.

The situation becomes richer in quantum many-body systems, where unitary evolution tends to generate entanglement, while measurements tend to suppress it. Their competition can drive the system between a highly entangled state and a localized, non-equilibrium state with little or no entanglement [1-4]. Such a *measurement-induced phase transition* provides a way to probe how information spreads in a quantum system that is not perfectly isolated, but is instead continuously monitored by its surroundings. This interaction with the environment leads to decoherence, which represents one of the central challenges for the realization of robust quantum processors.

Despite the fundamental interest of these transitions, detecting them experimentally is challenging because quantum measurements are intrinsically probabilistic. Averaging over measurement outcomes can wash out the transition, making it invisible in conventional ensemble-averaged observables. Instead, the transition is naturally characterized by quantum-information quantities such as entanglement entropy, which are nonlinear functions of the density matrix and depend on individual measurement records. Experimentally accessing these quantities therefore requires some form of postselection on measurement outcomes. In practice, this typically involves repeating the experiment many times to obtain sufficient statistics for a given measurement record. The number of repetitions required grows exponentially with system size and measurement time, making such an approach prohibitively costly for large systems.

A recent approach to circumvent this *postselection problem* is to relax the requirement of selecting a single, exact measurement record. Rather than retaining only trajectories corresponding to one specific sequence of measurement outcomes, one can consider a larger, but still restricted, ensemble of trajectories whose measurement records fall within a prescribed range of outcomes [5-6].

When applied to a many-body quantum system, this approach reveals a sharp change in the system's behavior as the size of the selected ensemble is varied. In particular, for sufficiently small ensembles, the resulting dynamics closely resemble those of a single postselected trajectory [5-6]. This suggests that certain properties of complex ensembles of quantum trajectories may be captured by individual, experimentally accessible trajectories, potentially providing a new way to study and control monitored quantum systems without requiring exponentially costly postselection.



A random quantum circuit consisting of entangled qubits that undergo unitary gate operations and quantum measurements while interacting with a noisy environment.

Objective: The objective of this research project is to investigate the interplay between partial postselection and conditional feedback in monitored many-body quantum systems. To explore these effects, we will consider a many-body system of non-interacting electrons undergoing entangling unitary evolution interrupted by disentangling quantum measurements. We will study

how the resulting dynamics are modified by local particle injection and depletion, as well as by local and non-local feedback protocols and adaptive partial postselection.

Project: These questions will be addressed using a combination of analytical and numerical methods. We will analytically study both the averaged Lindblad equation describing the monitored and dissipative dynamics and the non-Hermitian model associated with a single postselected trajectory. In parallel, we will numerically simulate quantum trajectories and characterize their dynamics using different measures of entanglement and quantum information.

Environment: The project will take place at SPMS lab at CentraleSupélec.

Contact: Interested candidates can send a CV, and motivation letter to:

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Extension: There is a possibility to extend this project to a doctorate thesis ([funding secured](#)).

Applicants Profile: A solid background in quantum mechanics and condensed-matter physics, including basic knowledge of second quantization. Background in many body physics and condensed matter theory. Proficiency in Python

Keywords: Entanglement entropy, measurements induced phase transition, open quantum systems.

References:

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[3] A. Chan, R. M. Nandkishore, M. Pretko, and G. Smith, Unitary- projective entanglement dynamics, *Phys. Rev. B* **99**, 224307 (2019).

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