

Exploring time-optimal quantum control in a cold-atom experiment

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Time-optimal quantum control is a promising approach for achieving effective quantum information processing, where rapid state transformations are engineered to mitigate decoherence effects. Quantum systems are inevitably subjected to environmental interactions that quickly degrade their quantum state, and in many cases they are also immersed in an always-on external field. The challenge is therefore to devise control schemes that steer the system amid dynamical ambient Hamiltonians while minimizing the operation time and exploiting these background fields whenever possible.

Building on recent work addressing this problem on a background Landau-Zener Hamiltonian [1], we are implementing the proposed time-optimal control protocols in a cold-atom platform. The experimental apparatus we are developing has now reached a stage that enables the manipulation of single qubits encoded in the clock states of the hyperfine ground-state manifold of ^{87}Rb atoms. Using microwave fields, we can simulate a particular background Hamiltonian while applying tailored control pulses that yield a targeted time-optimal state or gate transformation. After upgrading the setup, this single-qubit control will be extended to realize time-optimal two-qubit gates in an optical-tweezer array of Rydberg-interacting atoms.

We anticipate that progress on this front could critically expedite and reduce the energy cost of high-fidelity quantum operations, thereby extending the achievable coherent circuit depths. This could potentially represent a crucial step towards enabling quantum error-correction codes, which require operations to undercut specific error thresholds [2], and thus bring some of the exciting yet elusive quantum technology applications closer to realization.

[1] L.Garcia *et al.*, *Phys. Rev. Lett.* **129**, 180402 (2022).

[2] A.Steane, *Proc. R. Soc. Lond. A* **452**, 2551-2577 (1996).