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# Decoherence Noise on the Superconducting Qubits Training Program

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## Introduction

- Fermilab explores a unique quantum hardware scenario
  - SQMS Center conducts research on coupling superconducting qubits to ultrahigh-Q SRF cavities
    - Quantum information is stored in the cavity due to longer cavity coherence time - controlled with superconducting qubits
  - Small amounts of noise can lead to decoherence
    - Noisy Intermediate Scale Quantum (NISQ) Computing era
- The Superconducting Qubits Training Program (SQTP) [1] provides a visualization for beginners in quantum computing. The open quantum system simulated is a superconducting qubit coupled to a microwave cavity.
  - Parameter space:
    - Cavity frequency, qubit frequency, coupling strength
- The goal of this project is to add decoherence noise to rabi oscillations and observe decay of the cavity and qubit.

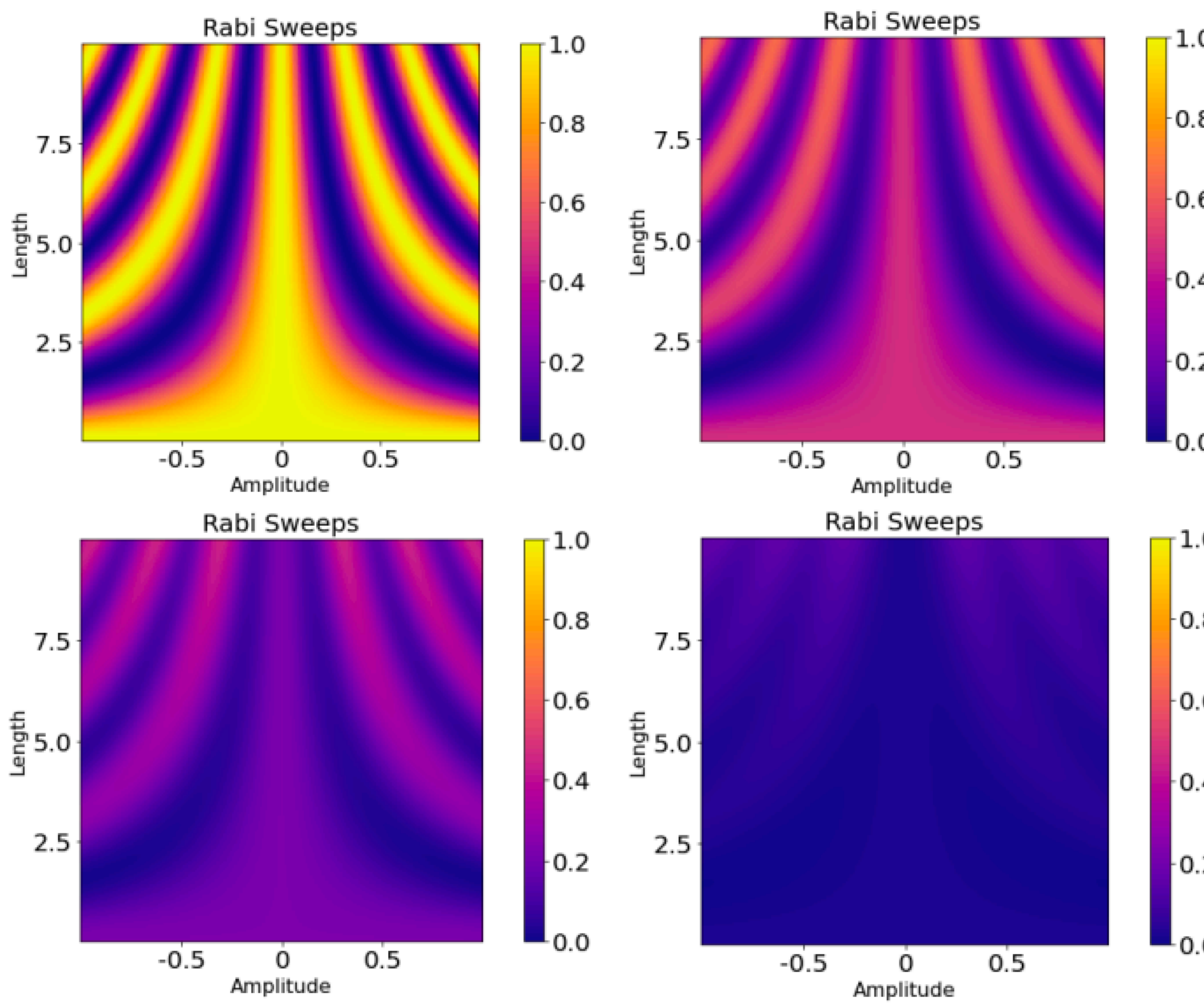


Figure 1: Rabi sweep of amplitude and length with varying gamma. The qubit, cavity, and interaction Jaynes-Cumming Hamiltonian are evolved by the Lindblad master equation. The qubit is driven by a square pulse and a σ- collapse operator is added. Gamma and kappa are qubit and cavity dissipation rates.

(a) Gamma = 0.00, (b) Gamma = 0.05, (c) Gamma = 0.10, (d) Gamma = 0.25

## Methods

- SQTP utilizes scQubits, NumPy, and QuTiP to observe the evolution of an open quantum system.
- All programs are open-source Python-based libraries.
- SQTP utilizes the Lindblad master equation solver
- SQTP uses the Rotating Wave Approximation (RWA) Jaynes-Cumming Hamiltonian

$$C_n = \sqrt{\gamma_n} A_n$$

Equation 1: Relationship between the collapse operators (σ- and a) and dissipation rates (gamma/kappa) in QuTiP [2]

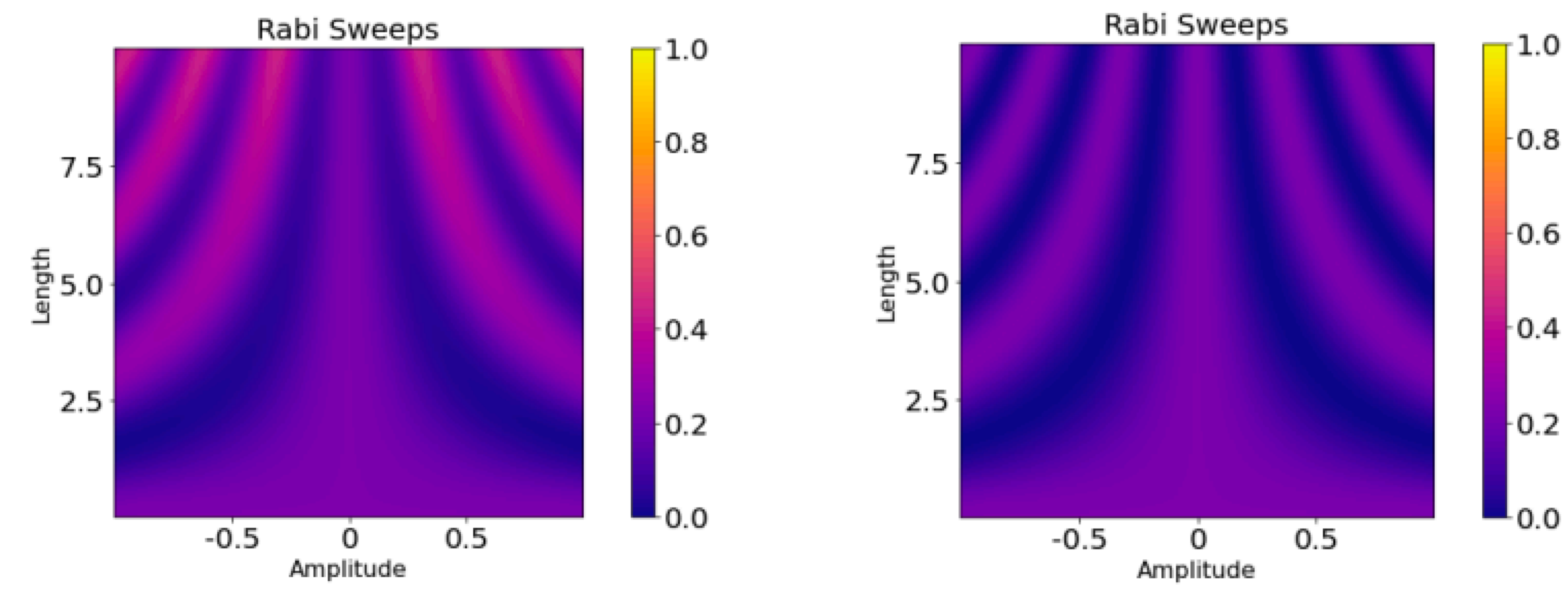


Figure 2: Rabi sweep of amplitude and length showing the qubit decays faster than the cavity. The qubit, cavity, and interaction Jaynes-Cumming Hamiltonian are evolved by the Lindblad master equation. A different collapse operator is added in each case. Gamma and kappa are qubit and cavity dissipation rates.

(a) The qubit is driven by a square pulse and σ- collapse operator is added, Gamma = 0.1
(b) The cavity is driven by a square pulse and annihilation (a) collapse operator is added, Kappa = 0.1

## Conclusion

- Simulated an open quantum system with the RWA Jaynes-Cumming Hamiltonian
- Showed decay of qubit and cavity with one collapse annihilation operator using varied gamma and kappa.
- Showed qubit decays faster than cavity
- Changed formatting to include tensor product in Hamiltonian section rather than in collapse operator section

## Future Projects

- Introduce a lower temperature
- Introduce an automatic tlist given amplitude range and difference between cavity and qubit frequencies
- Introduce a projector to track the state of the qubit and cavity separately
- Simulate the likelihood of the qubit being in the excite state and cavity in the second Fock state

## References


[1] Blowers, Ben (2021). *Superconducting Qubits Training Platform.* SULI Program at Fermilab.

[2] QuTiP (2024). *Lindblad Master Equation Solver.* Users Guide - Time Evolution and Quantum System Dynamics.


## Acknowledgment


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