Journal Club 09/05/2025

Coherence of a hole spin flopping-mode qubit in a circuit quantum electrodynamics environment

Léo Noirot,[1] Cécile X. Yu,[1,2] José C. Abadillo-Uriel,[3,4] Étienne Dumur,[1] Heimanu Niebojewski,[5] Benoit Bertrand,[5] Romain Maurand,[1] and Simon Zihlmann[1]

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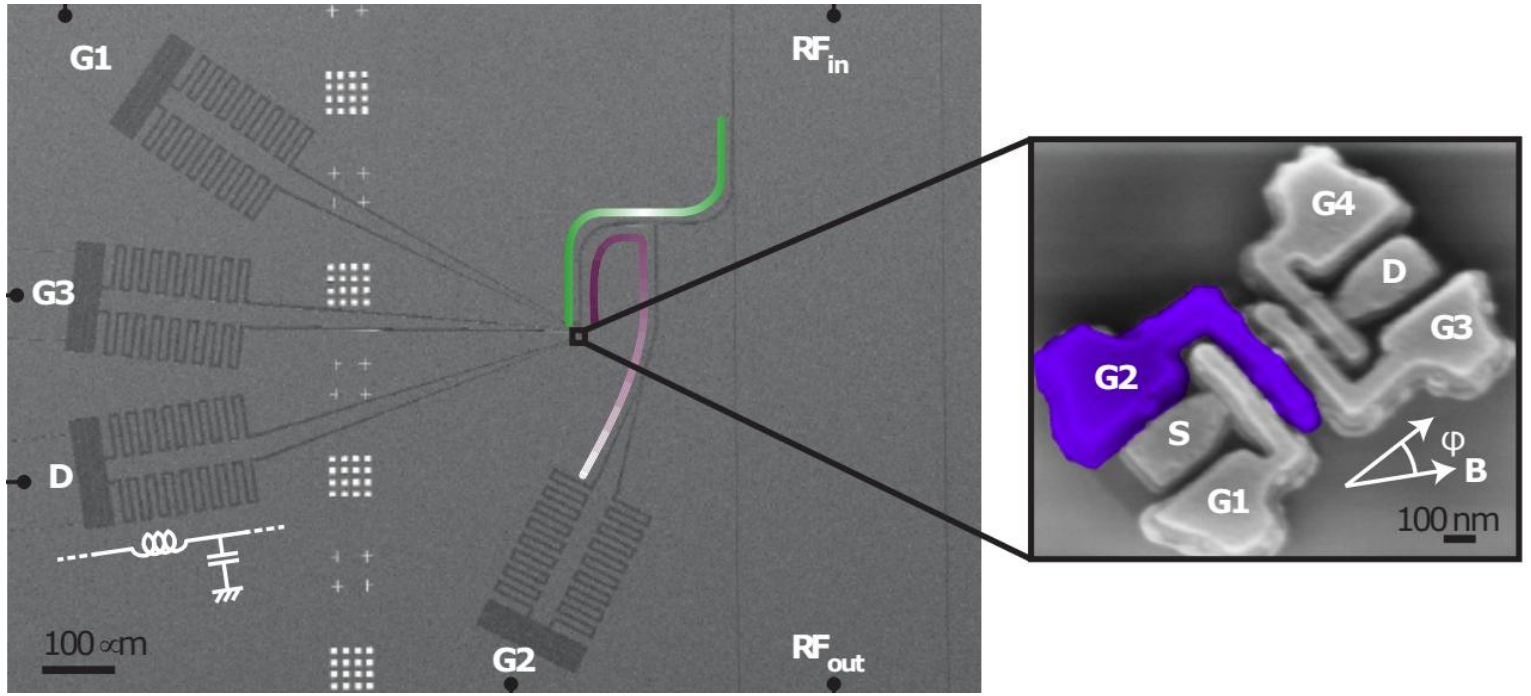
(Dated: March 17, 2025)

Key Highlights

- Achieve practical Flopping-Mode (FM) Hole Spin Qubit in Silicon Channel
- Strong Spin-Photon coupling using a High-Impedance Microwave Resonator
- Achieved Fast and Coherent Qubit Operations (f_{Rabi} ~ 100 MHz & T^e_2>1μs)
- Identification of limiting Decoherence Mechanisms: Photonic mechanisms

Experimental Setup

Natural Silicon channel, coupled to a high-impedance niobium nitride (NbN) microwave resonator



Setup:
- T_{base} = 8 mK
- TWPA+HEMT

Resonator:
- 10 nm NbN film
- Resonator Q_L = 402
- Resonator f_r = 5.413 GHz

Misc:
- Low Pass Filter Cut-off: 1.2 GHz

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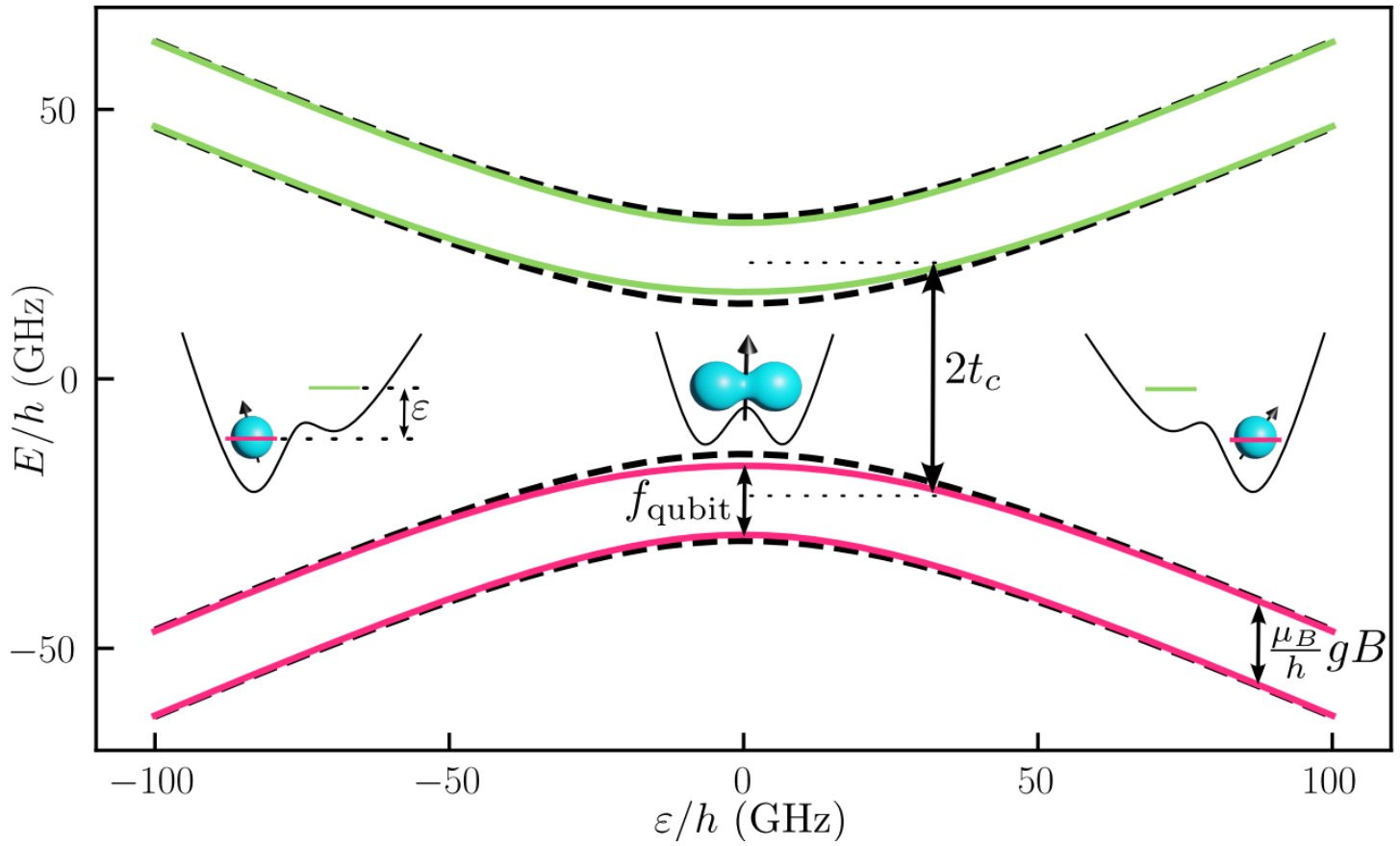
Flopping-Mode (FM) Qubits



- Single excess charge in double dot
- Finite magnetic Field
- SOI

- Large Electric Dipole
- Fast electrical control
- Detuning sweet spot

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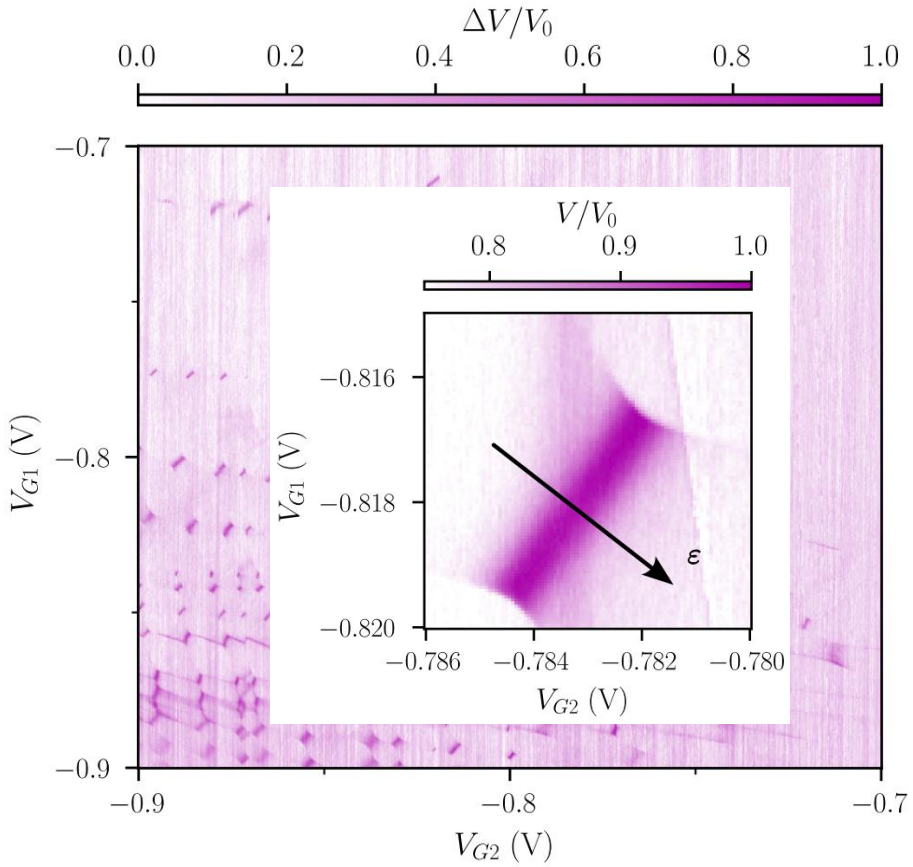
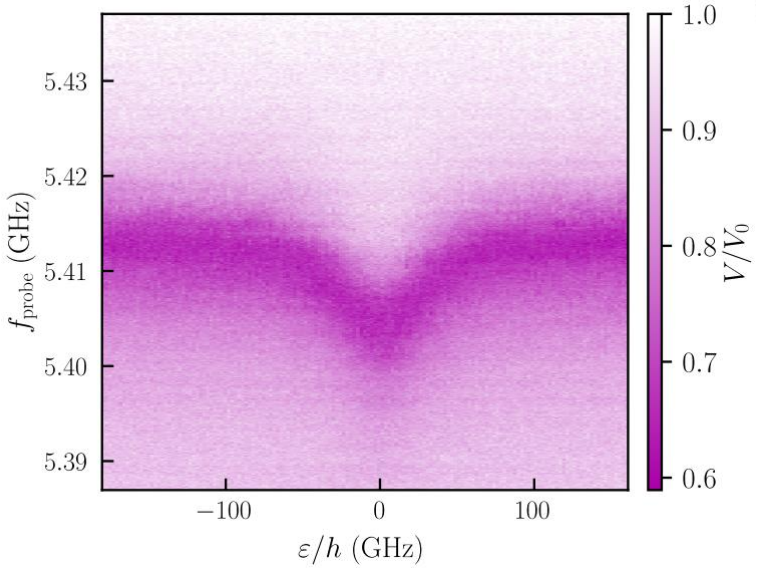
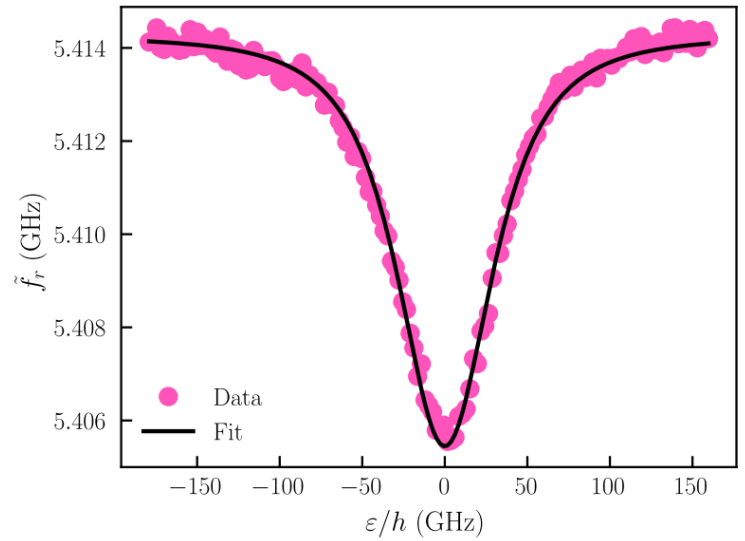
Charge Qubit







$$\chi_c = \frac{g_c^2 d_c^2}{2\pi}\left(\frac{1}{|f_c - f_{r,1}|} + \frac{1}{f_c + f_{r,1}}\right)$$

$g_c/2\pi$ = 437 ± 10 MHz
t_c/h = 22 ± 1 GHz.

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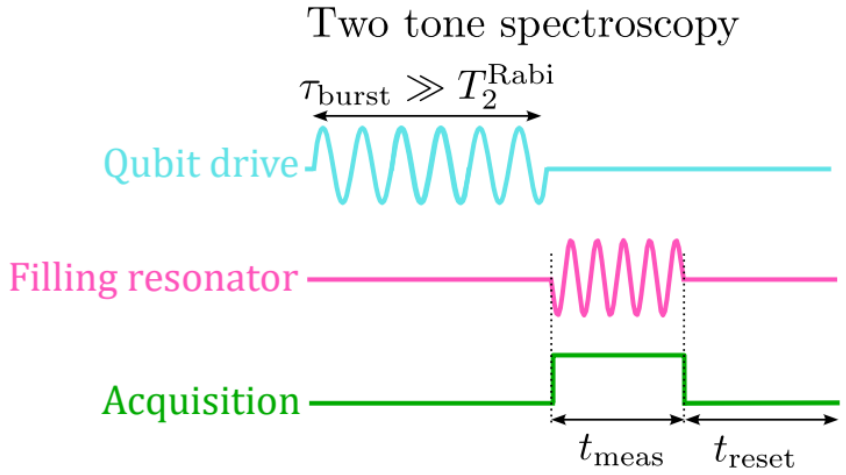
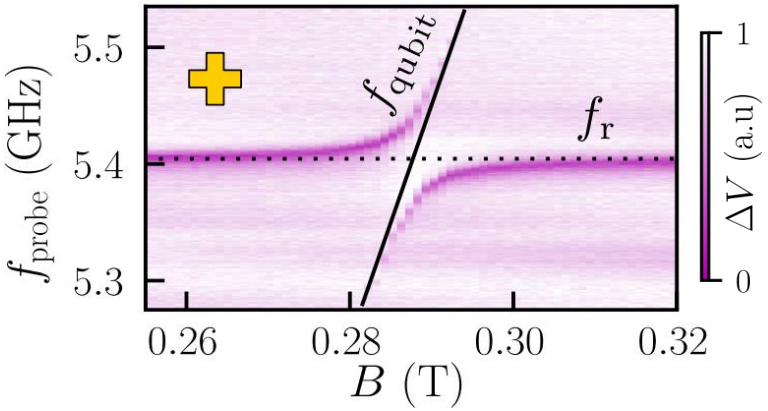
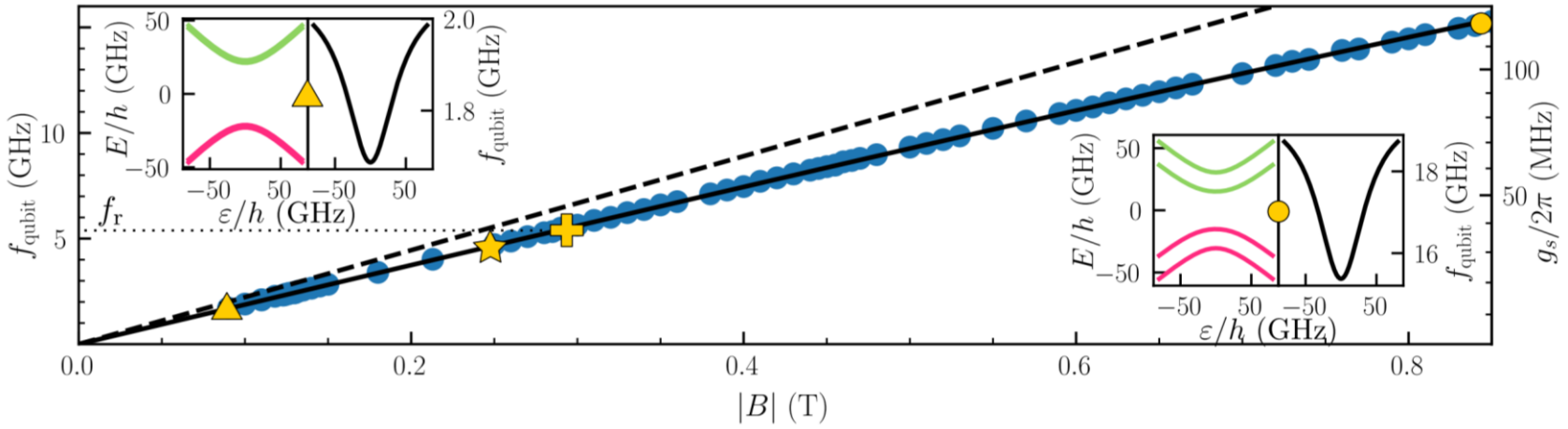
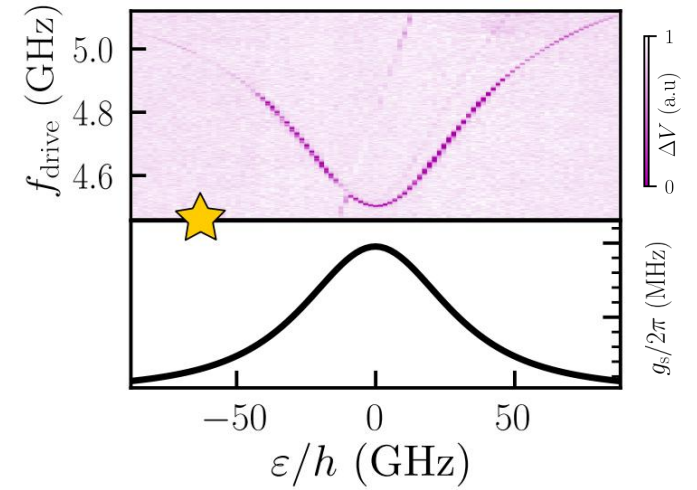
Flopping-Mode Hole Spin Qubit









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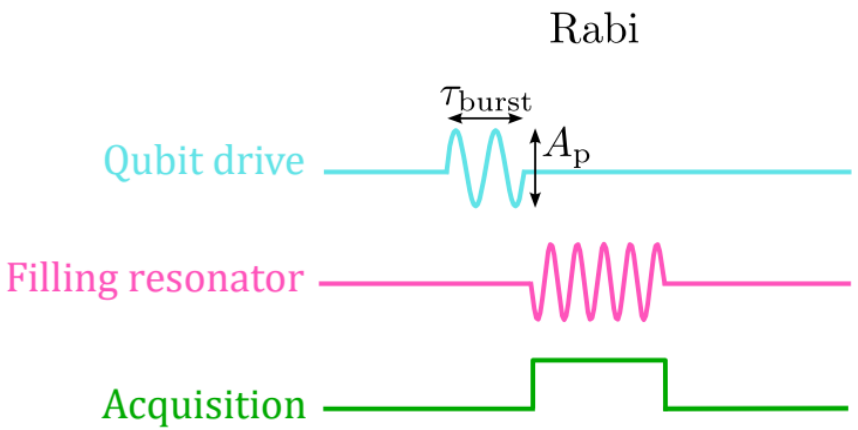
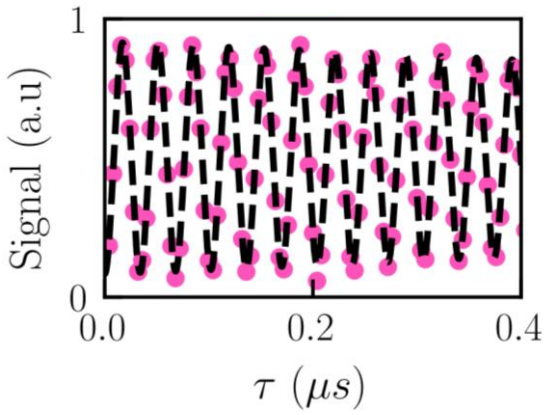
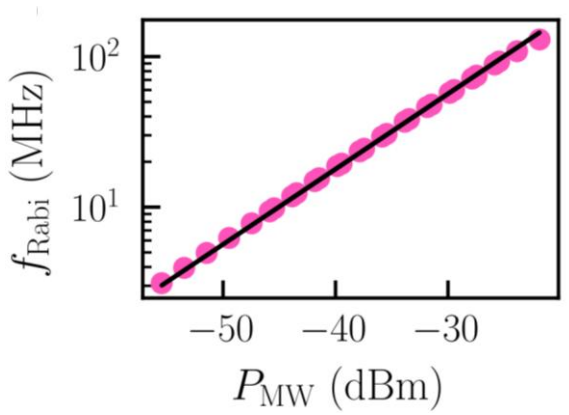
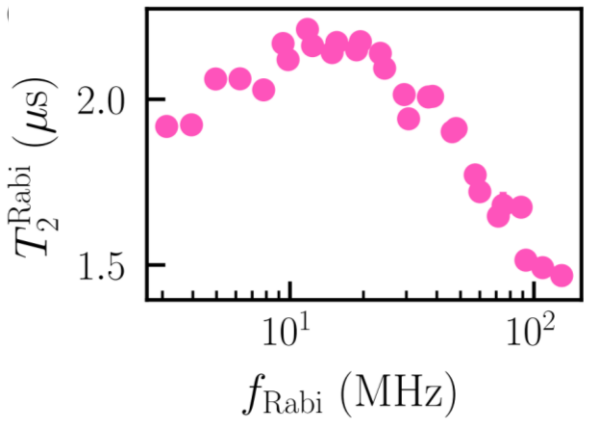
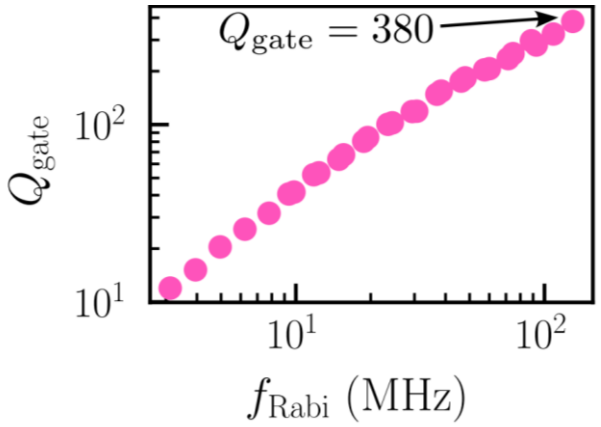
Result: Qubit performance











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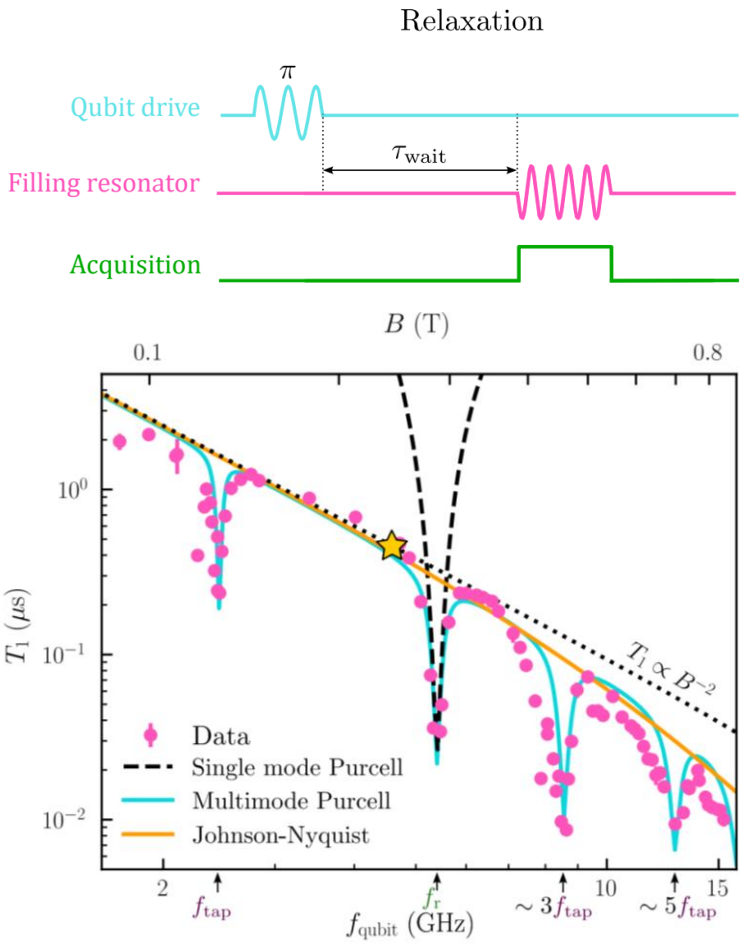
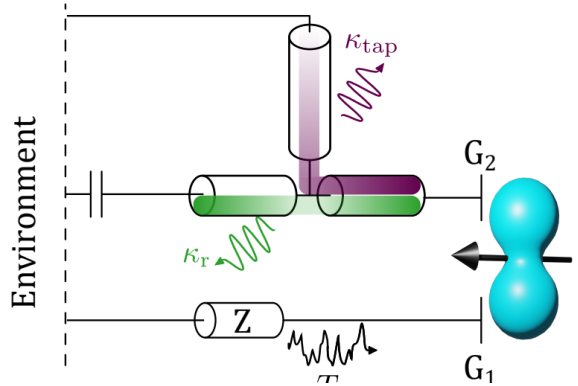
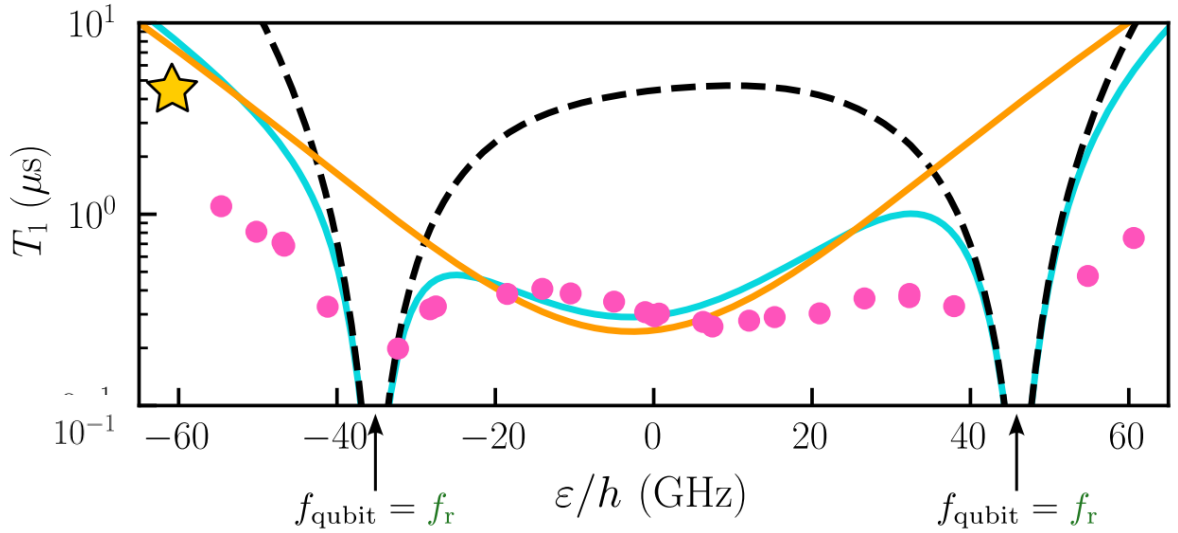
Results: Relaxation By Photon Emission





300 Ω at 200 mK



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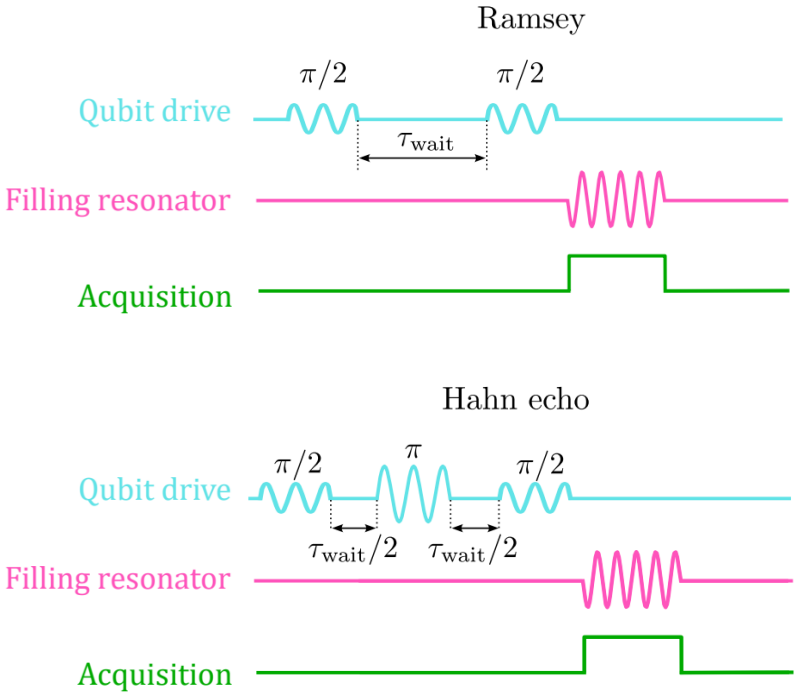
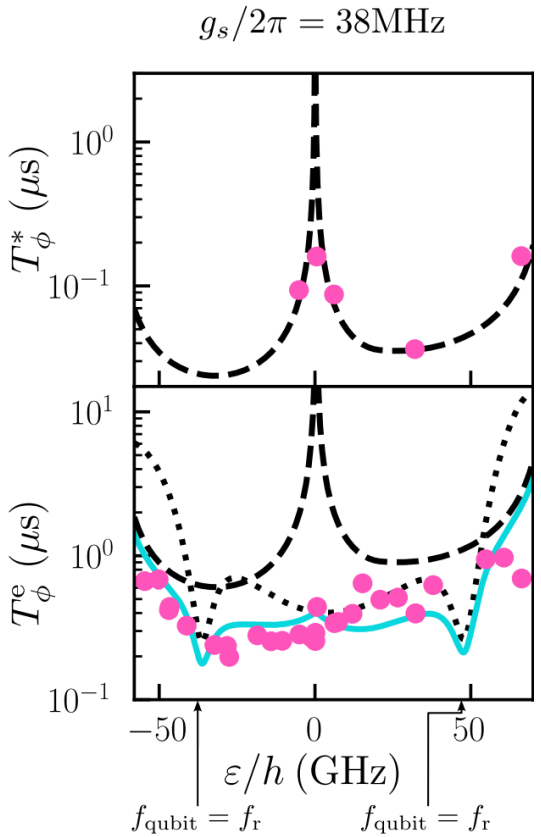
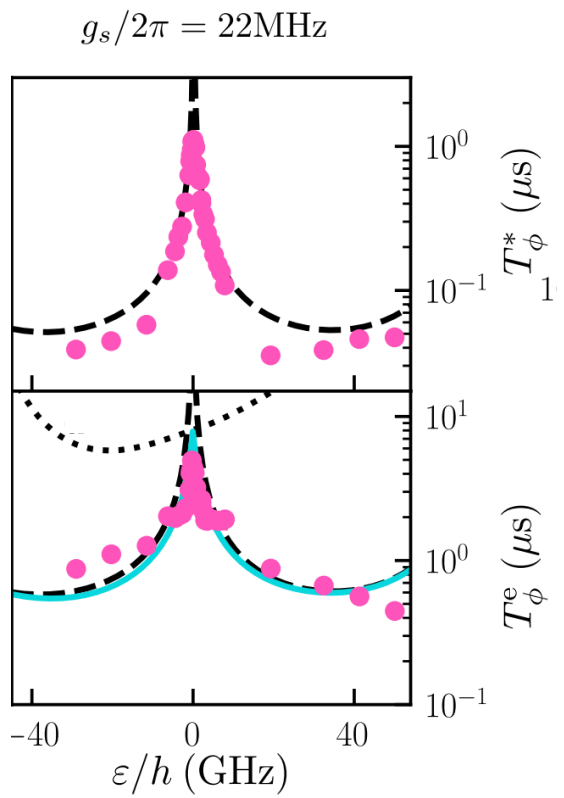
Results: Photon Shot-Noise Dephasing







Data — Charge — Photons — Charge + photons

Resonator temp.:80 mK
DC tap temp.: 230 mK

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Summary

- Demonstration of Flopping-Mode (FM) Hole Spin Qubit with gate quality factor of **380**
- Achieve High-speed control: f_{Rabi}>100MHz
- Strong spin-photon coupling regime: g_s: 10 - 100 MHz
- Identified Radiative decay as relaxation mechanism
- and thermal photon shot noise as the decoherence mechanism

Outlook

- Better **filtering & shielding** → Reduce photon temperature → increase dephasing time (by ~20×)
- Add **Purcell filters**, **high-Q cavities**, **microwave engineering**
- **Isotropic purification** of silicon → Reduce hyperfine dephasing

- **Phonon-induced relaxation** remains unobserved, needs exploration.

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