Detecting leakage in integer fluxonium qubits

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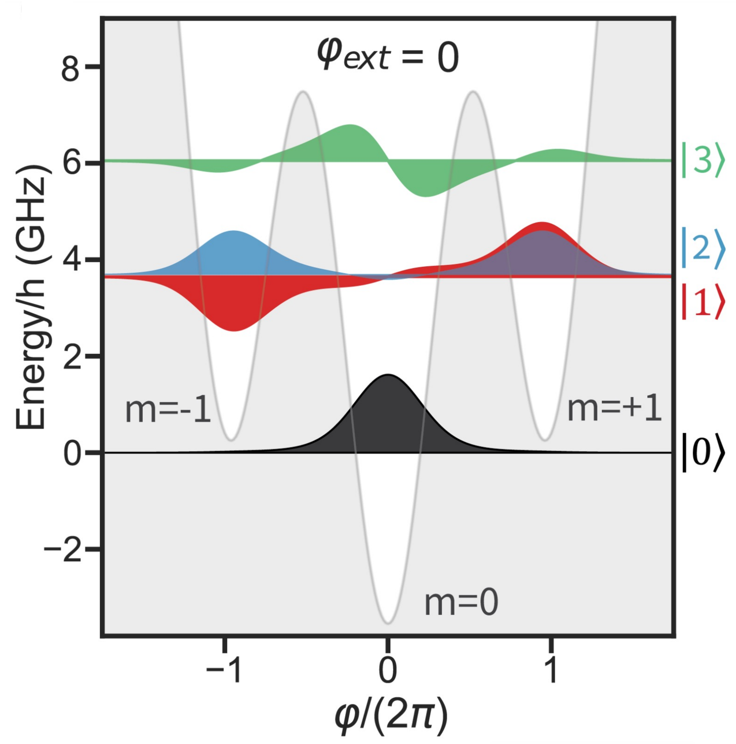
Motivation

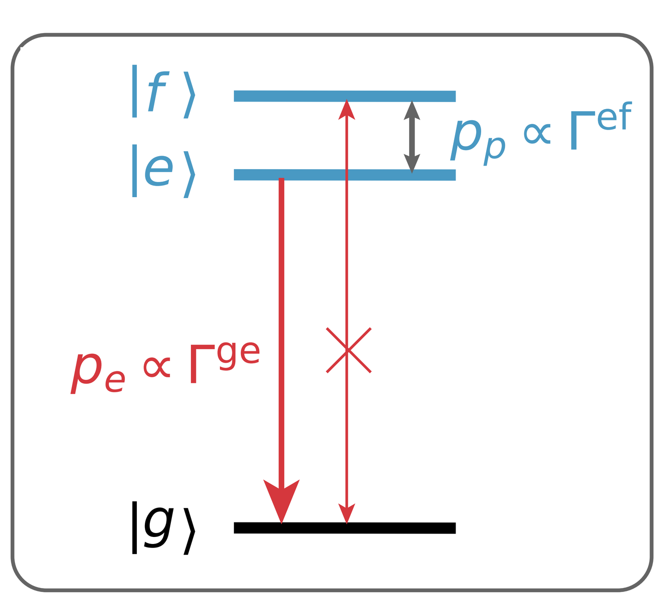
1. Integer fluxonium has a leakage issue, we may want to detect leakage instead of using leakage reduction units
2. Leakage detection enables new configurations of computational subspace



Qubit configuration

e-f integer fluxonium

1. e-f subspace is very low-frequency (amplitude of consecutive single well tunneling)
2. Far smaller charge matrix element
3. Long coherence time when capacitive loss is the dominant source of error

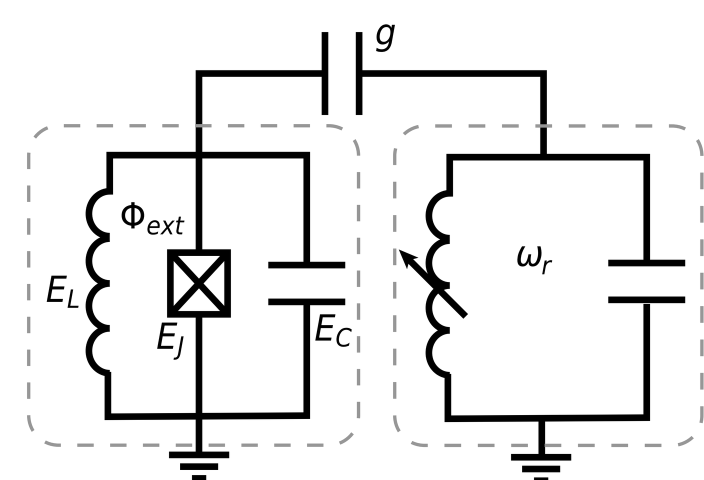


Choosing resonator frequency

Setup

Frequency tunable resonator

Capacitive coupling in the dispersive regime

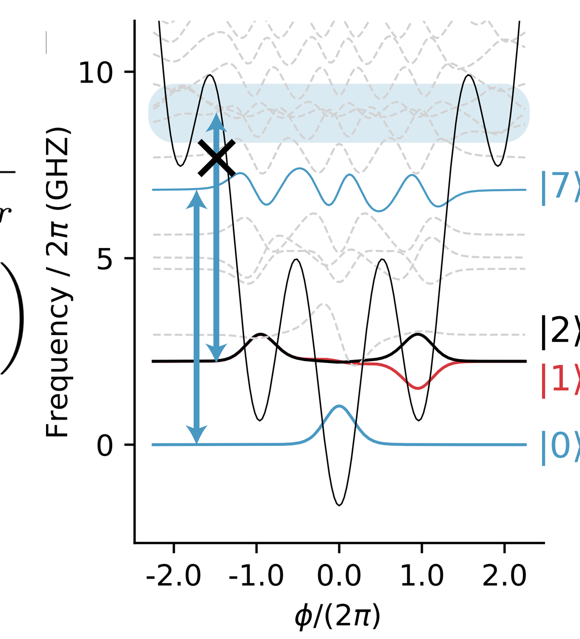


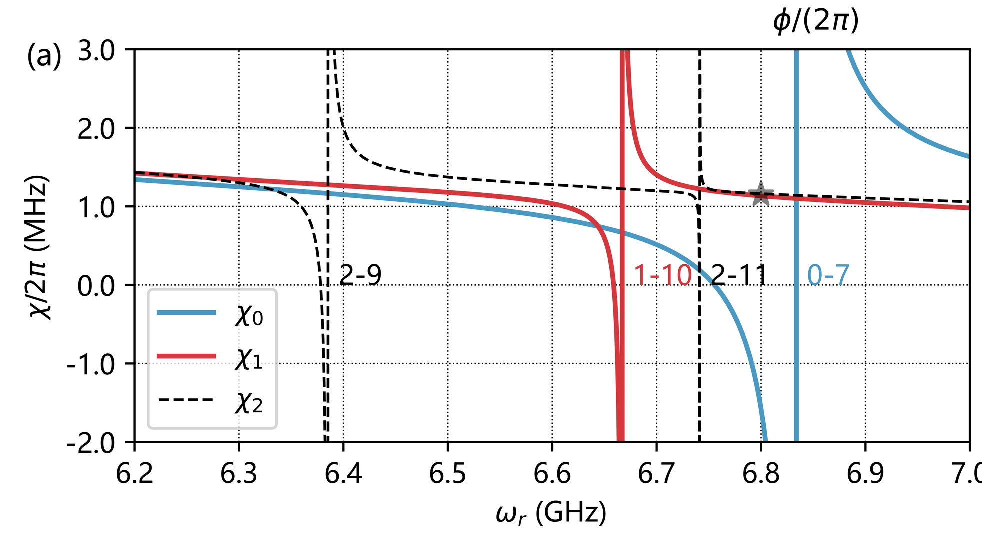
Requirements for leakage detection

$$\chi_L \neq \chi_1, |\chi_1 - \chi_2| \approx 0$$

Leveraging fluxonium selection rule

$$\chi_j = g^2 \sum_i \left(\frac{|\langle i|\,\hat{n}_q\,|j\rangle|^2}{\omega_j - \omega_i - \omega_r} + \frac{|\langle i|\,\hat{n}_q\,|j\rangle|^2}{\omega_j - \omega_i + \omega_r} \right)$$

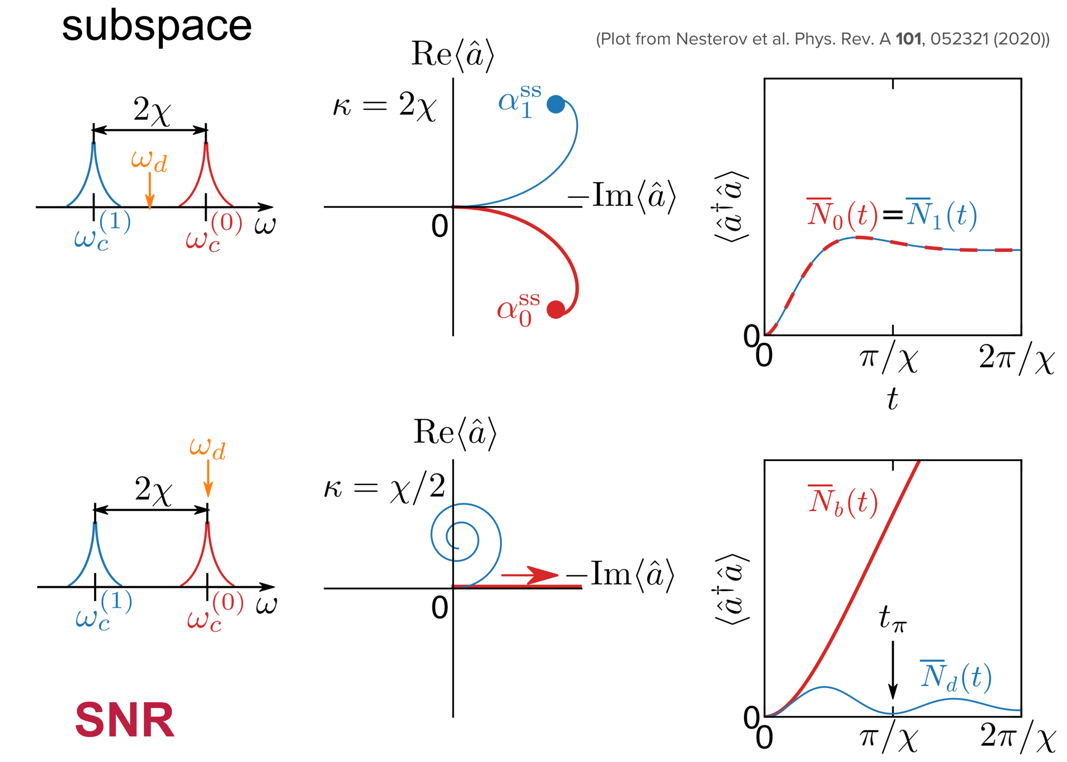




Choosing how to drive & SNR

Non-conventional drive frequency and time

To reduce dephasing in computational subspace



SNR

Option-1, Simple criterion in terms of field in resonator:

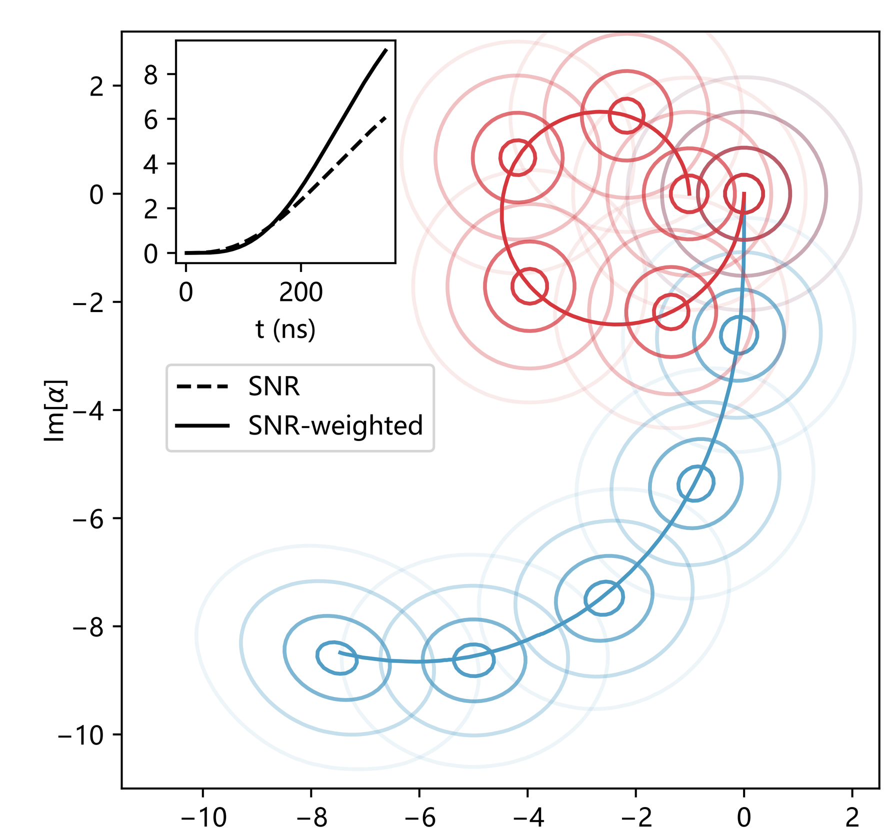
$$\alpha^{out}_{a/b} = \alpha^{in} + \sqrt{\kappa}\alpha_{a/b}$$

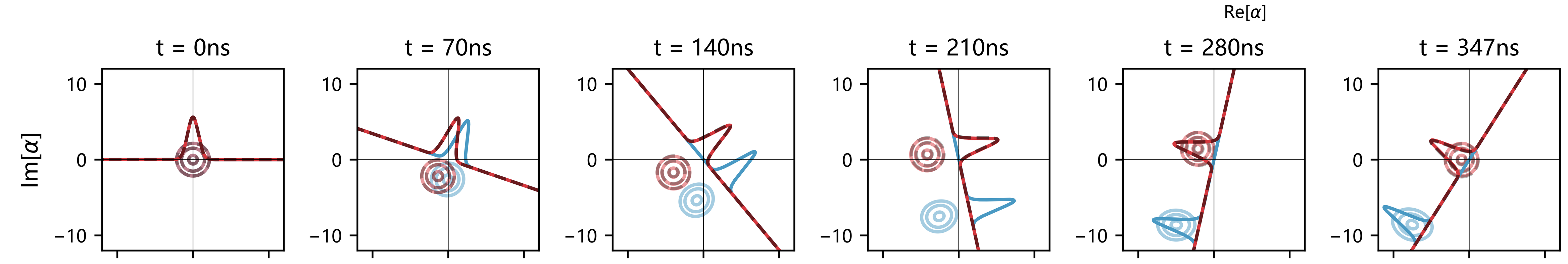
$$|\hat{M}_a(\tau) - \hat{M}_b(\tau)| = \hat{M}(\tau) = \sqrt{\kappa}\int_0^\tau |\alpha^{out}_a(t) - \alpha^{out}_b(t)|dt,$$

$$SNR(\tau) = \frac{|\hat{M}_a(\tau) - \hat{M}_b(\tau)|}{[\delta\hat{M}_a(\tau) + \delta\hat{M}_b(\tau)]^{1/2}}.$$

$\kappa\tau/2$

Option-2 using Q-function to simulate distribution of instantaneous readout signal





Effect on computational subspace

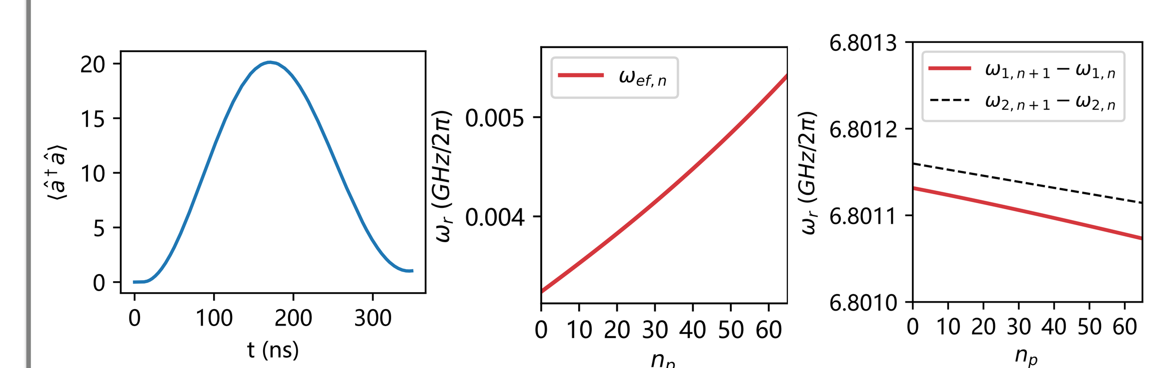
Error analysis

Dephasing:

1. Coherent phase-smearing:

Without decay, 10^{-3} error rate

$$\langle e^{i\Lambda n t}\rangle = e^{i\Lambda \bar{n} t} e^{-\frac{1}{2}(\Lambda \bar{n} t)^2}$$



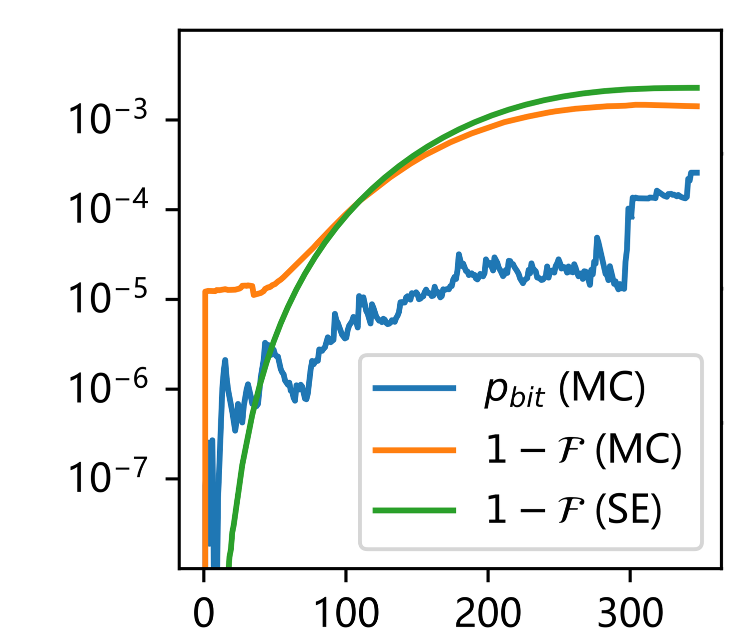
2. Measurement rate / readout dephasing / loss of information to output field:

Very small

$$Re[\rho_{ab}] = \frac{2\epsilon^2\kappa(\chi_a - \chi_b)^2}{(4(\Delta+\chi_a)^2+\kappa^2) + (4(\Delta+\chi_b)^2+\kappa^2)}$$

Amplitude damping:

Observed more bit-flip when decay is on, but less than phase-smearing



Outlook

- Fluxonium readout is messy! Can we use another type of circuit element?
- Experimentally measure the coherence time
- What else is possible with IFQ fluxonium?