



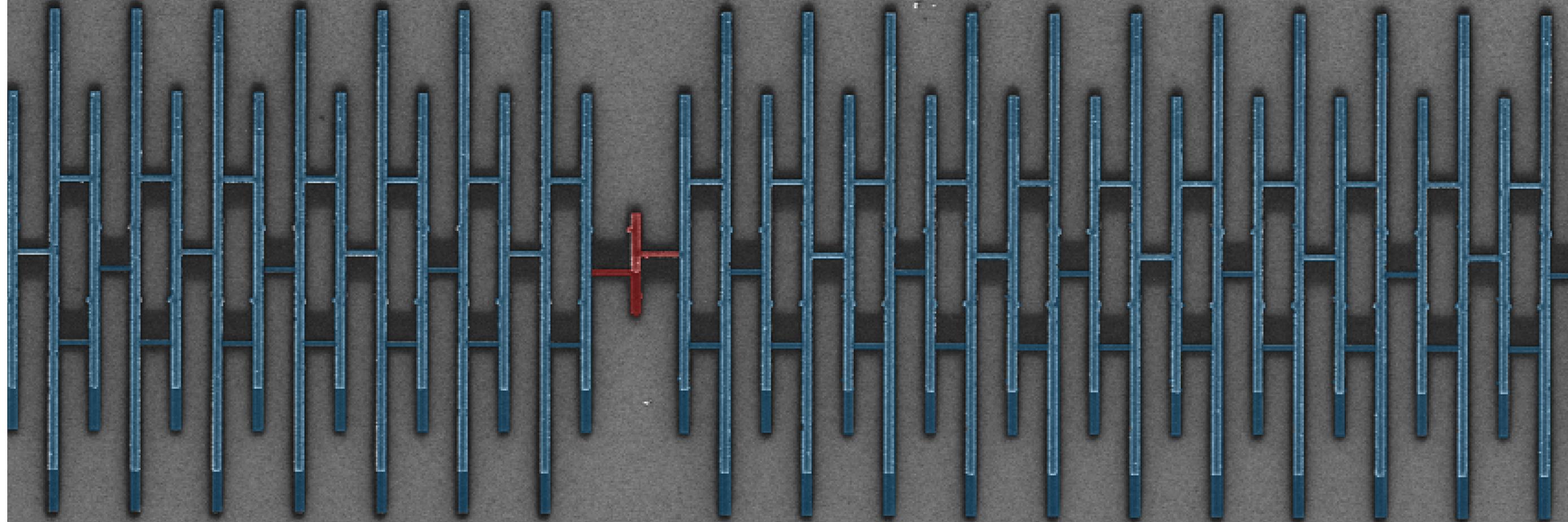
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SILENT
WAVES

High-Impedance Circuits, Superinductances and Fluxonium Qubits

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2025 Spring School on
Superconducting Qubit Technology

10µm

Diagonalising the Fluxonium Hamiltonian: scQubits

Search the docs ...

GETTING STARTED

- Install
- GUI
- Basics

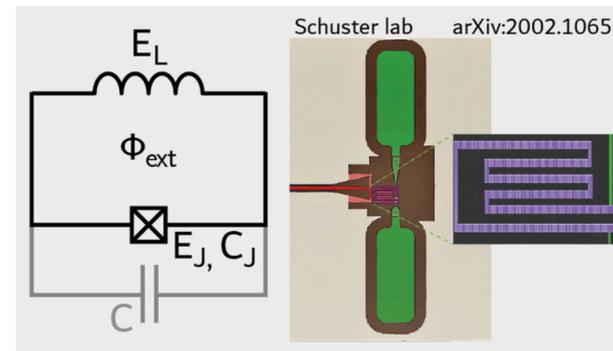
COMMON QUBITS, CIRCUITS

Qubits

- Transmon
- TunableTransmon
- Fluxonium

- scqubits.Fluxonium.hamiltonian
- scqubits.Fluxonium.eigenvals
- scqubits.Fluxonium.eigensys
- scqubits.Fluxonium.get_spectrum_vs_param
- scqubits.Fluxonium.wavefunction
- scqubits.Fluxonium.plot_wavefunction
- scqubits.Fluxonium.n_operator
- scqubits.Fluxonium.phi_operator
- scqubits.Fluxonium.exp_i_phi_operator
- scqubits.Fluxonium.cos_phi_operator
- scqubits.Fluxonium.sin_phi_operator
- scqubits.Fluxonium.matrixelement_table

Fluxonium



The Hamiltonian of the fluxonium qubit [Manucharyan2009] in phase basis representation is given by

$$H = -4E_C\partial_\phi^2 - E_J \cos(\phi - \varphi_{\text{ext}}) + \frac{1}{2}E_L\phi^2.$$

Here, E_C is the charging energy, E_J the Josephson energy, E_L the inductive energy, and $\varphi_{\text{ext}} = 2\pi\Phi_{\text{ext}}/\Phi_0$ the external flux in dimensionless form. The **Fluxonium** class internally uses the E_C - E_L harmonic-oscillator basis [Zhu2013] with truncation level specified by **cutoff**.

An instance of the fluxonium qubit is created as follows:

```
fluxonium = scqubits.Fluxonium(EJ = 8.9,  
                                EC = 2.5,  
                                EL = 0.5,  
                                flux = 0.33,  
                                cutoff = 110)
```

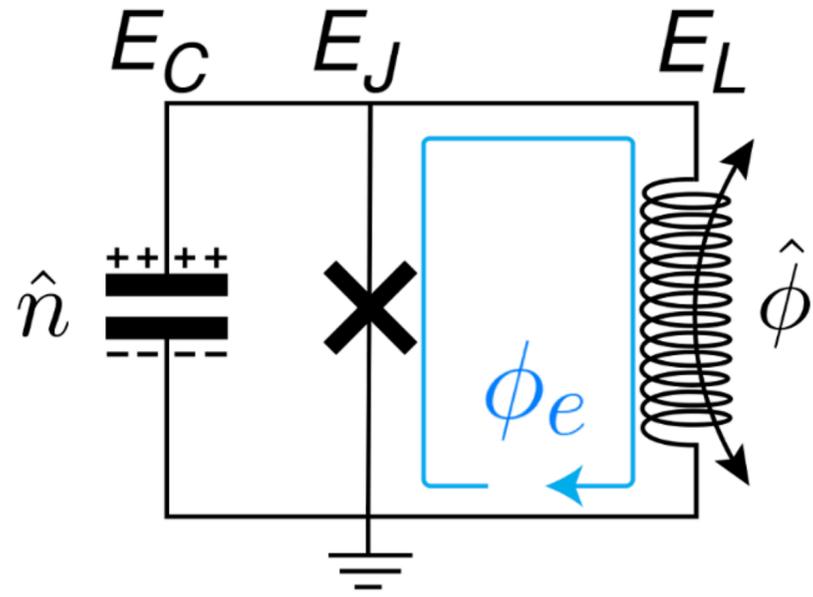
On this page

- Calculational methods related to Hamiltonian and energy spectra
- Wavefunctions and visualization of eigenstates
- Implemented operators
- Computation and visualization of matrix elements
- Estimation of coherence times

Edit this page

latest

Fluxonium: standard parameters



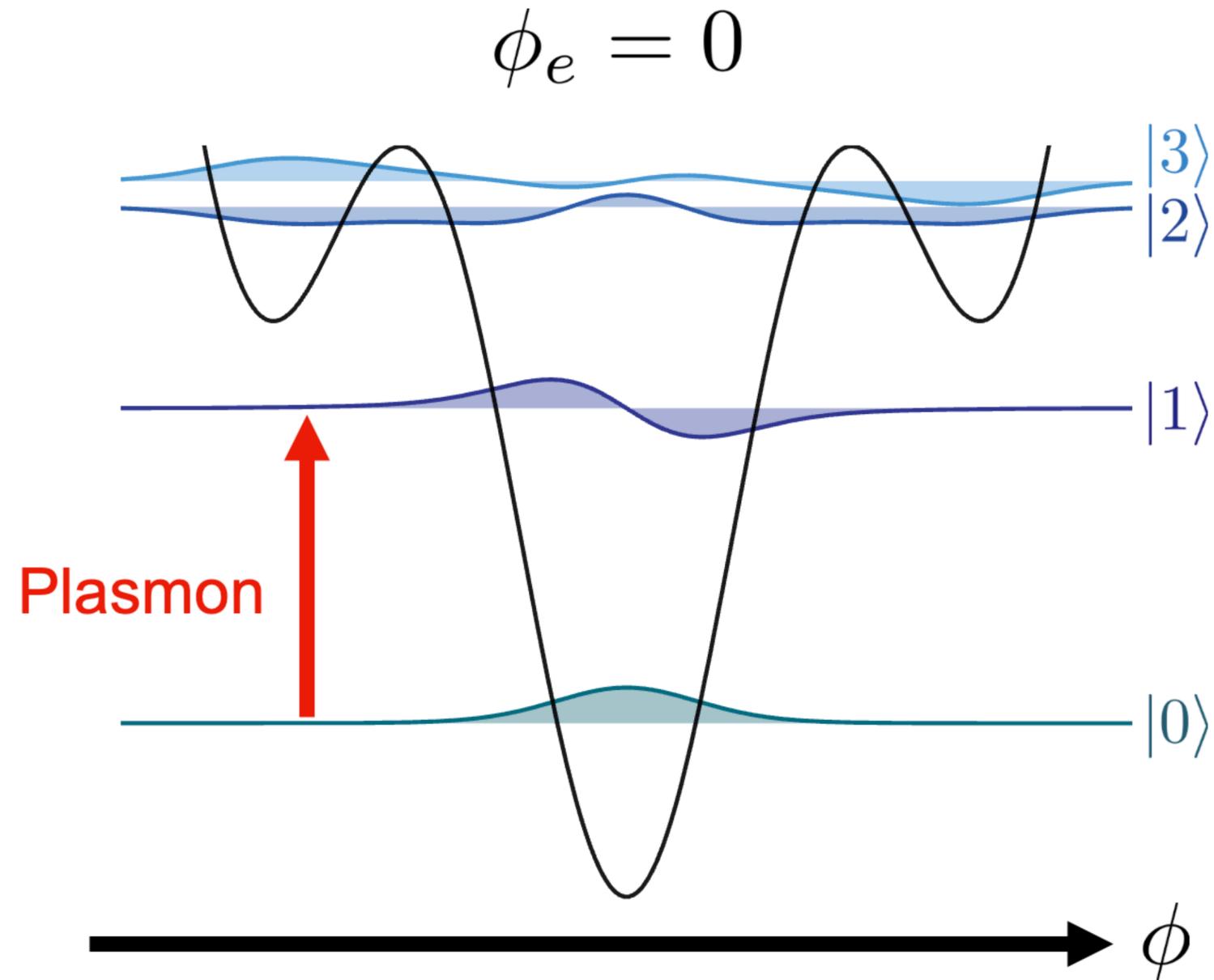
$$E_L \ll E_J$$

$$1 \lesssim E_J/E_C \lesssim 10$$

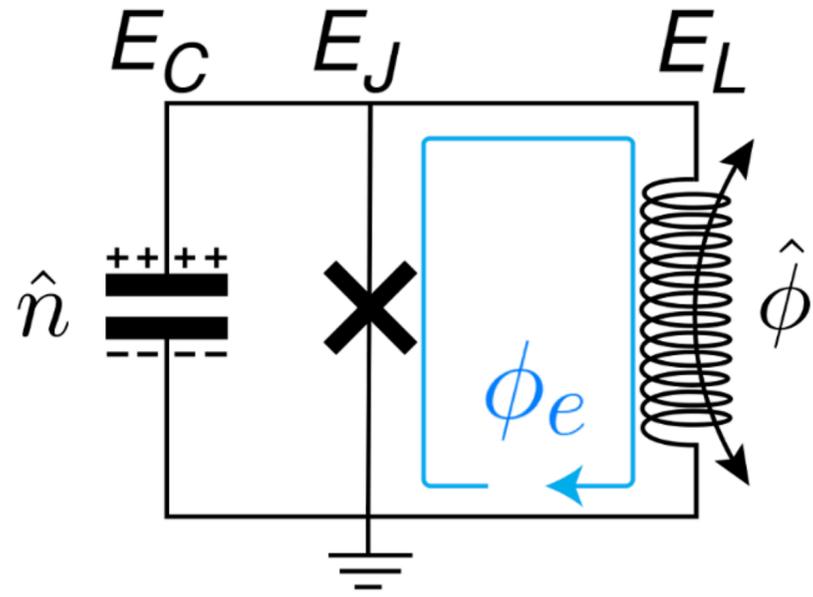
$$E_C/h = 1.08 \text{ GHz}$$

$$E_L/h = 0.64 \text{ GHz}$$

$$E_J/h = 5.57 \text{ GHz}$$



Fluxonium: standard parameters



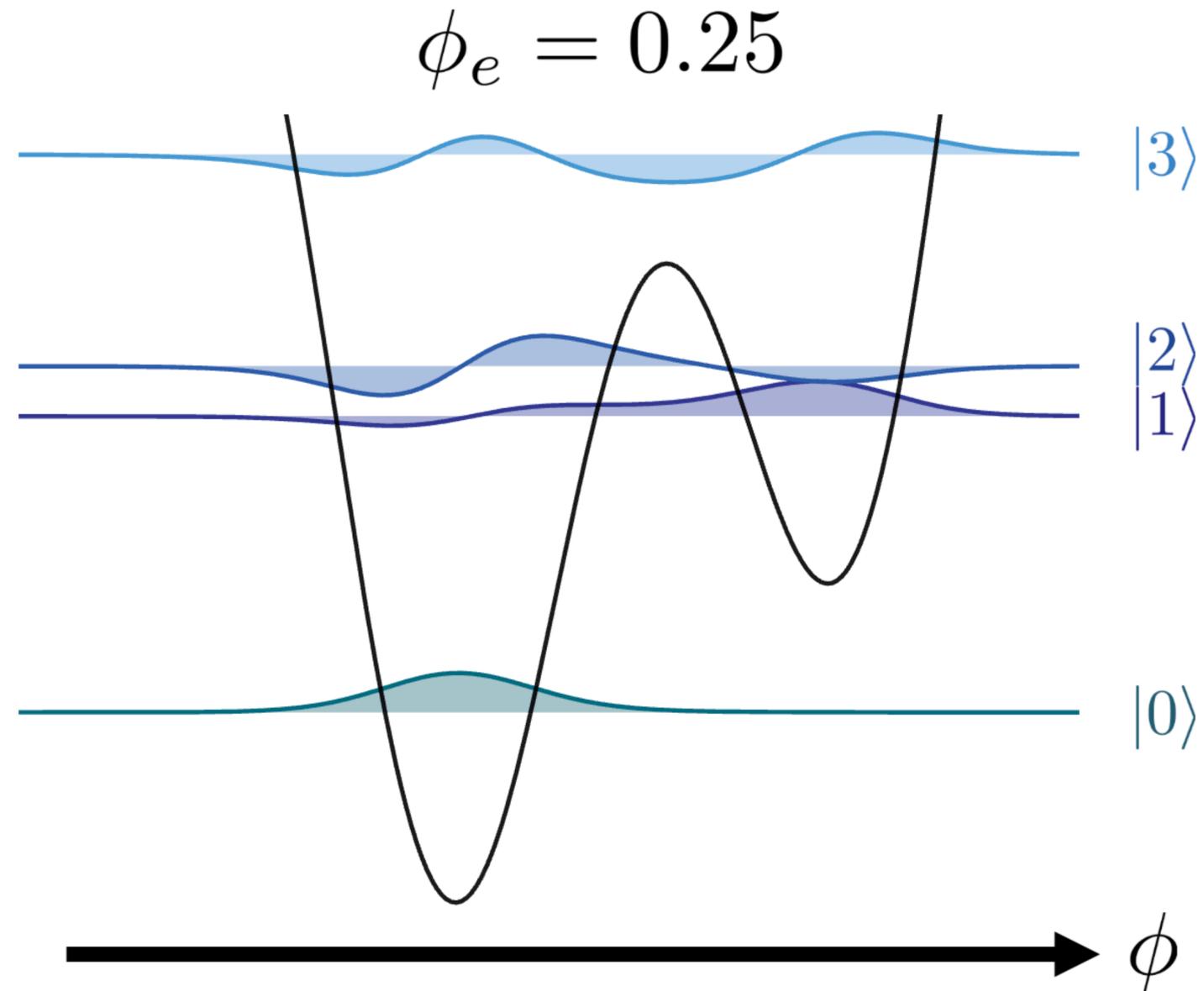
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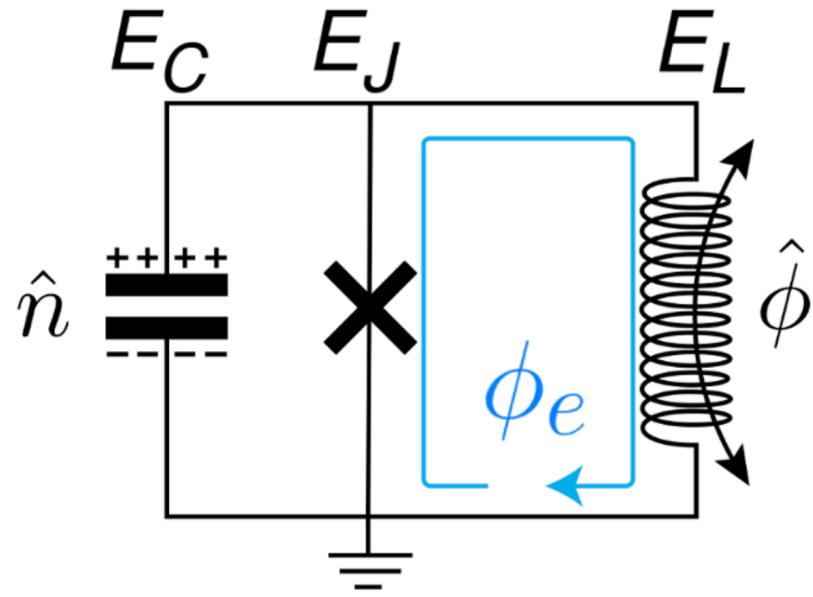
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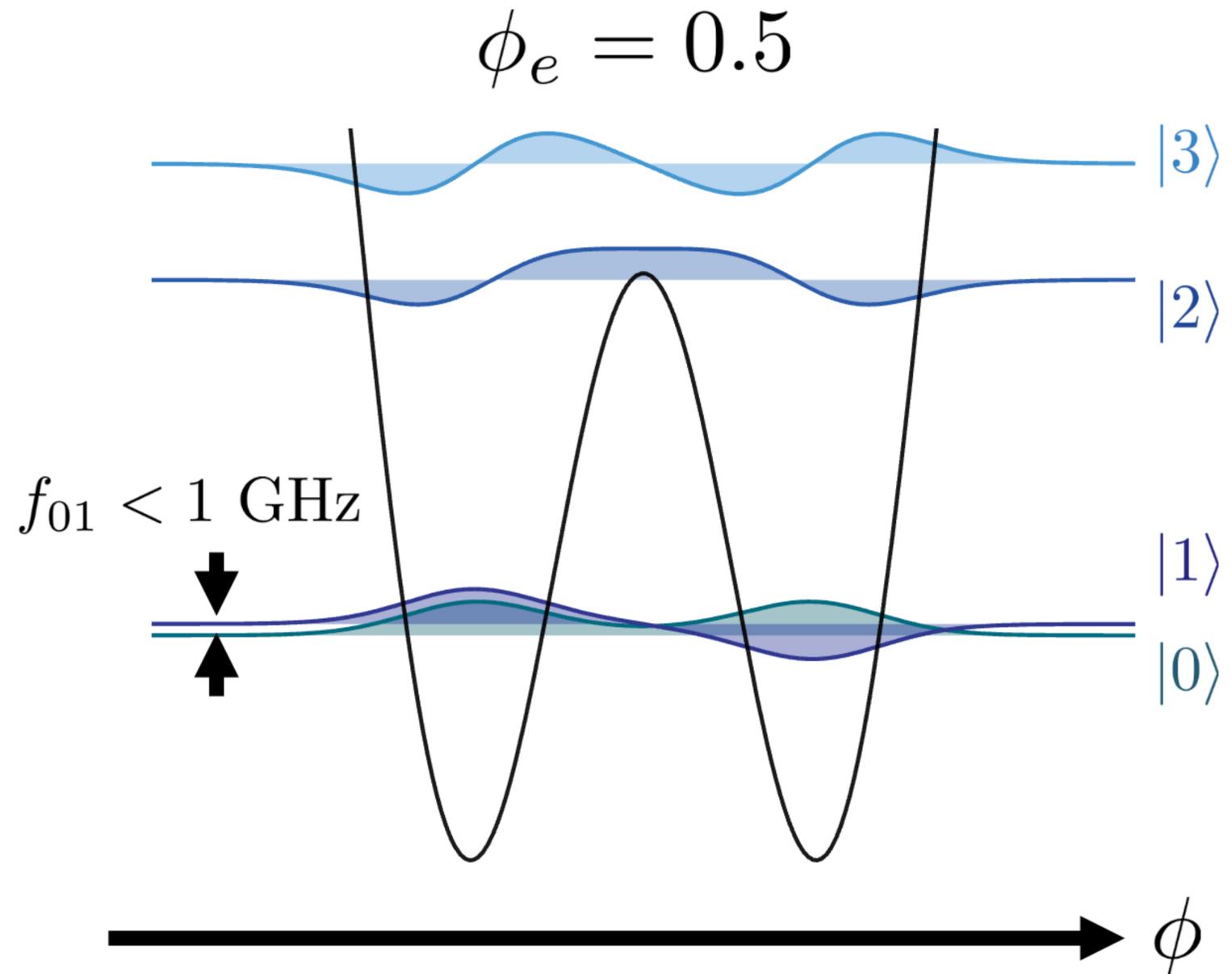
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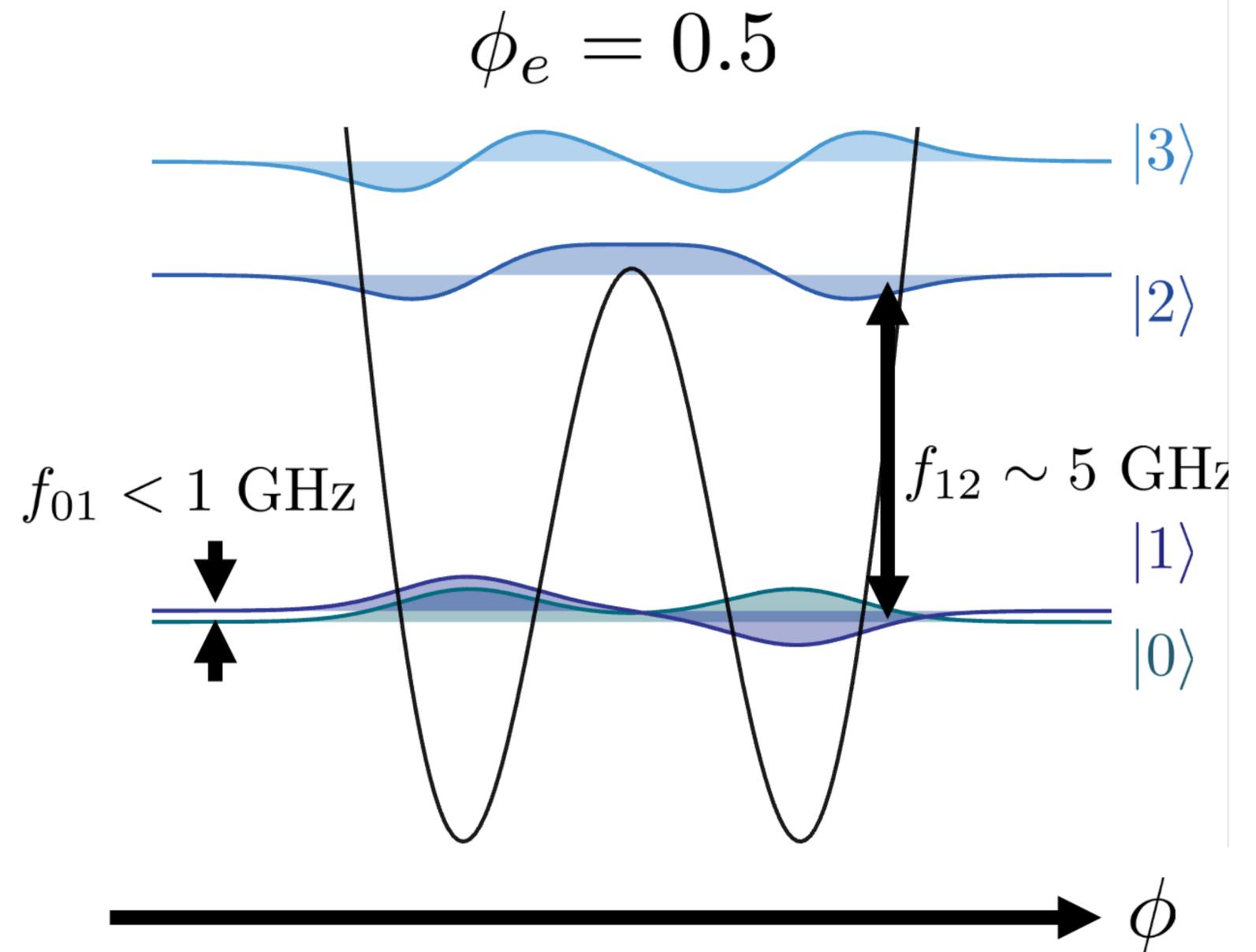
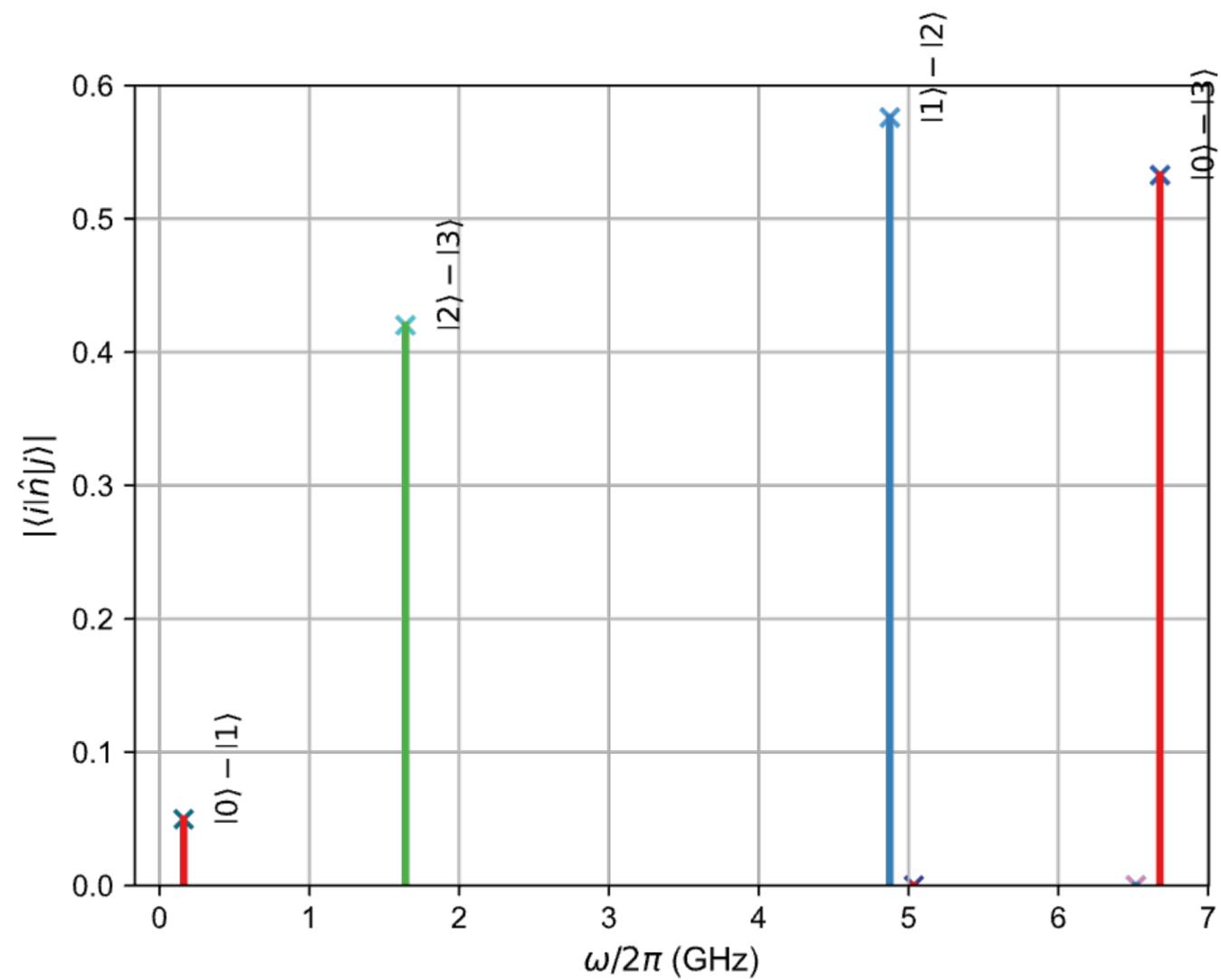
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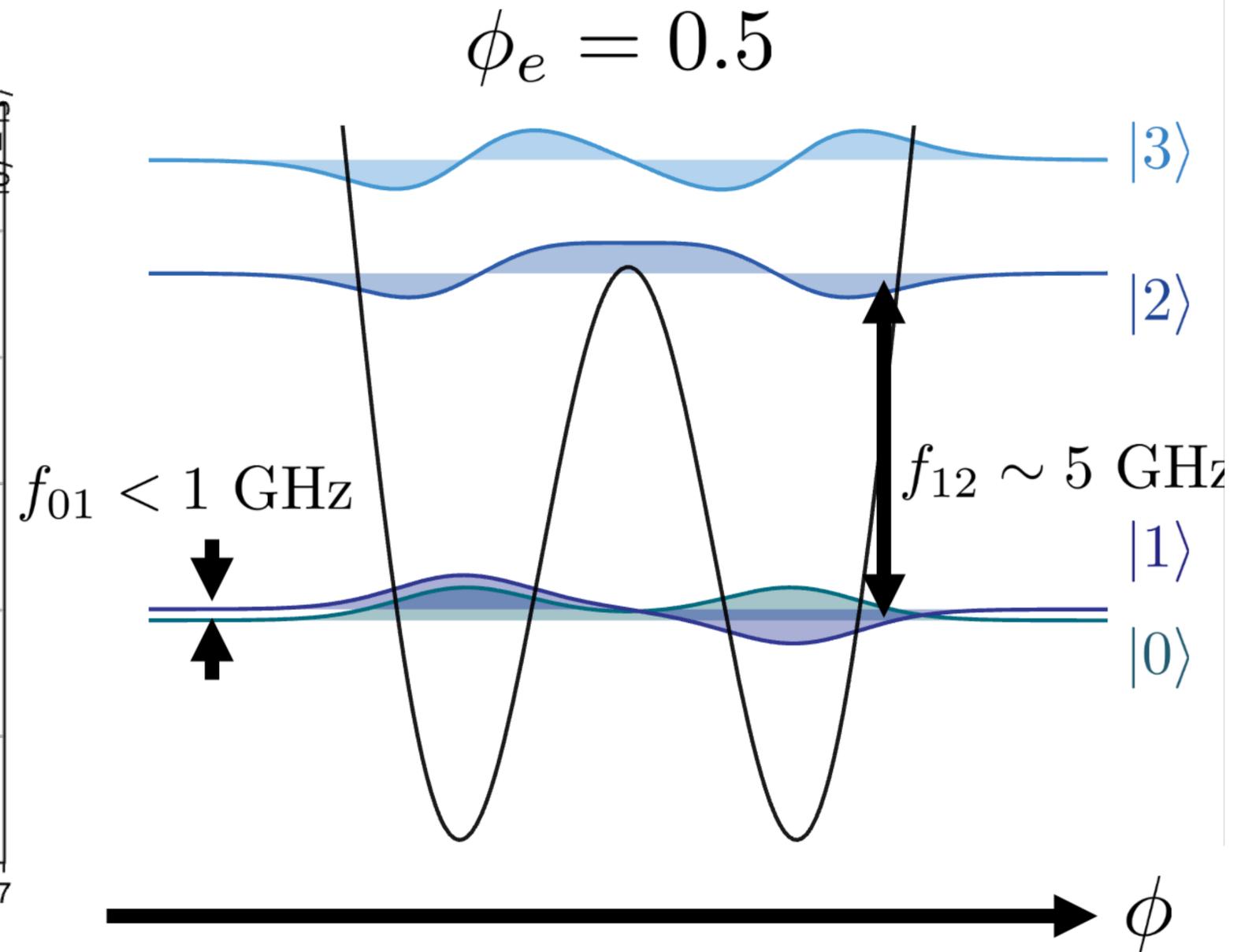
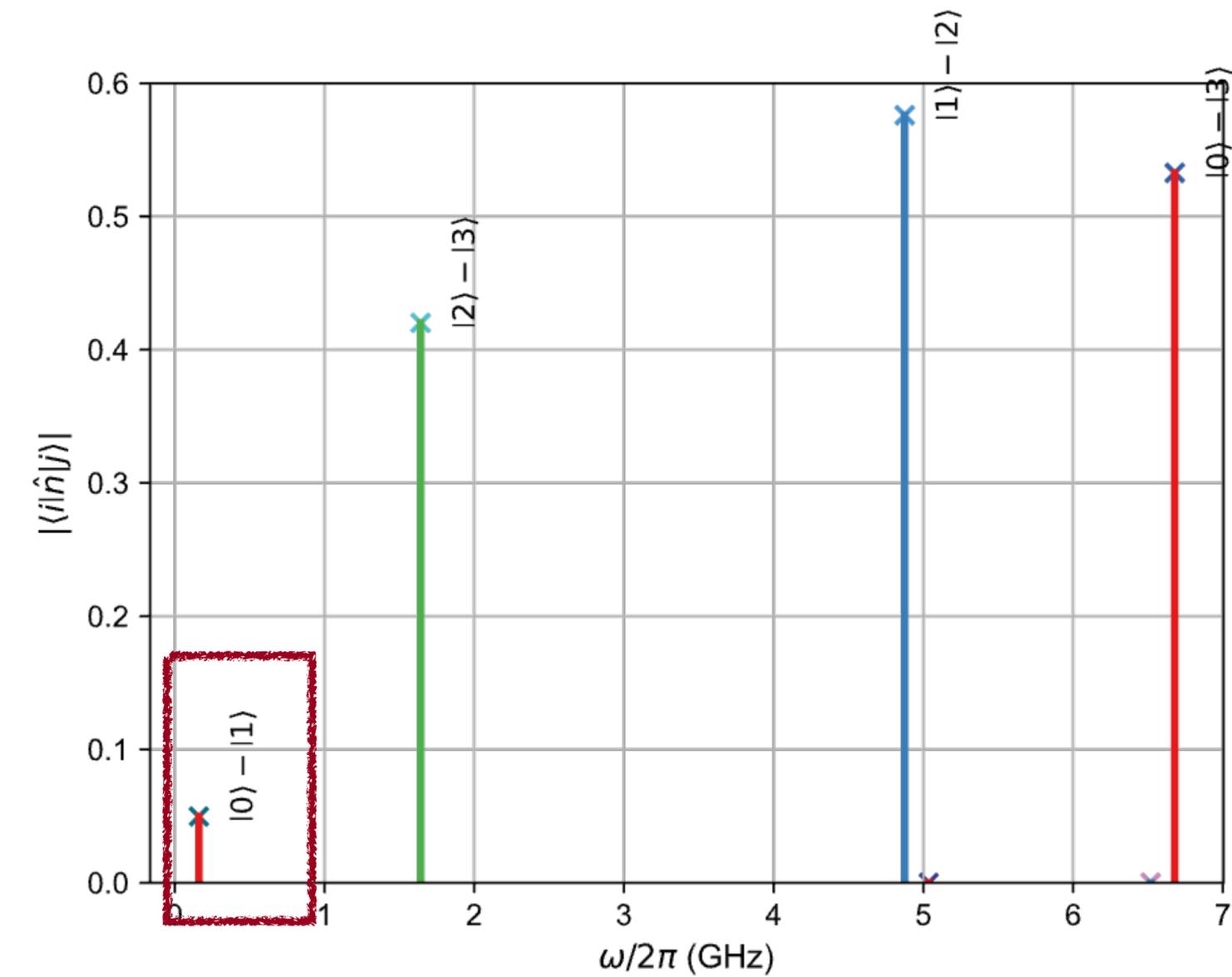
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Fluxonium: standard parameters

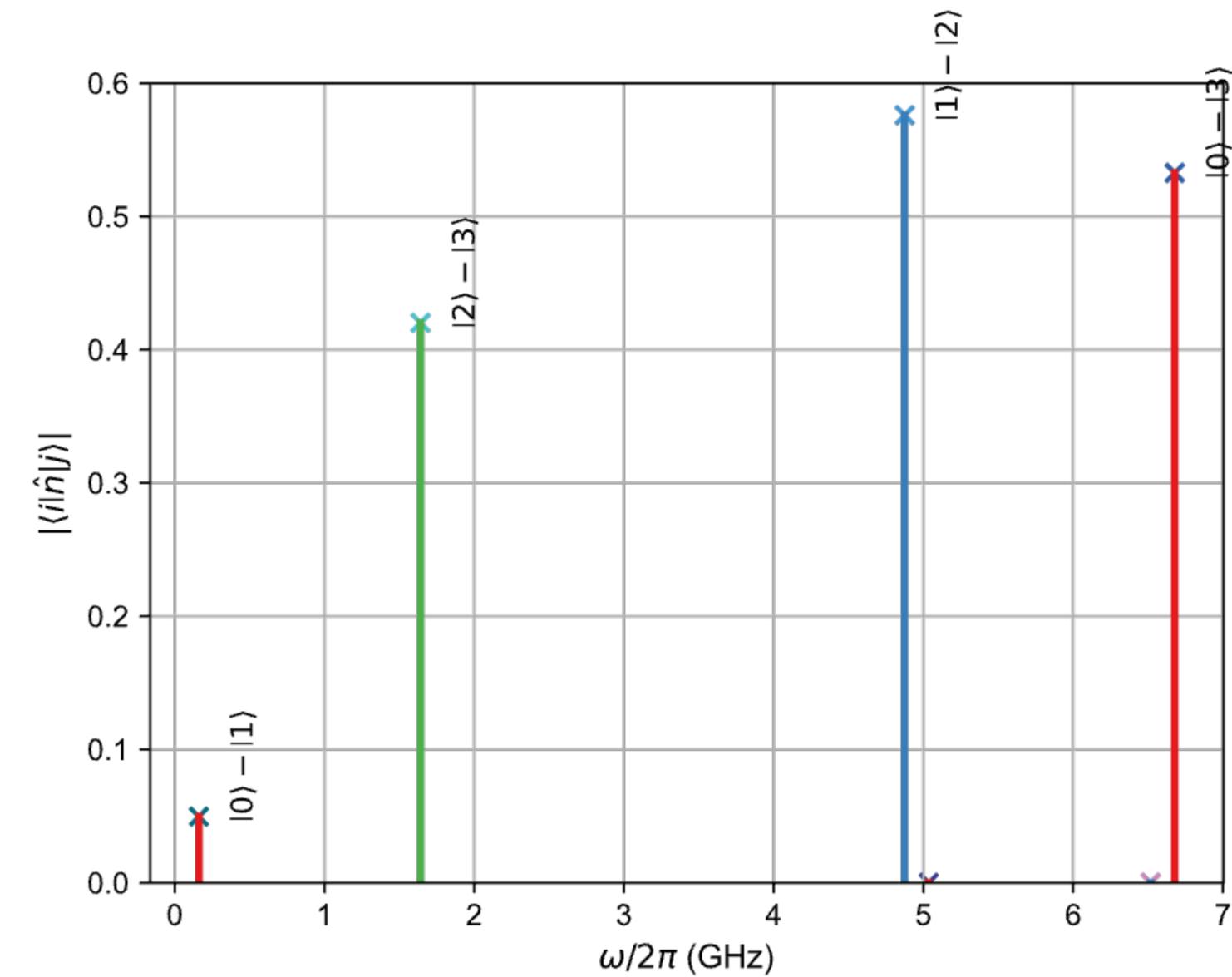


Fluxonium: standard parameters

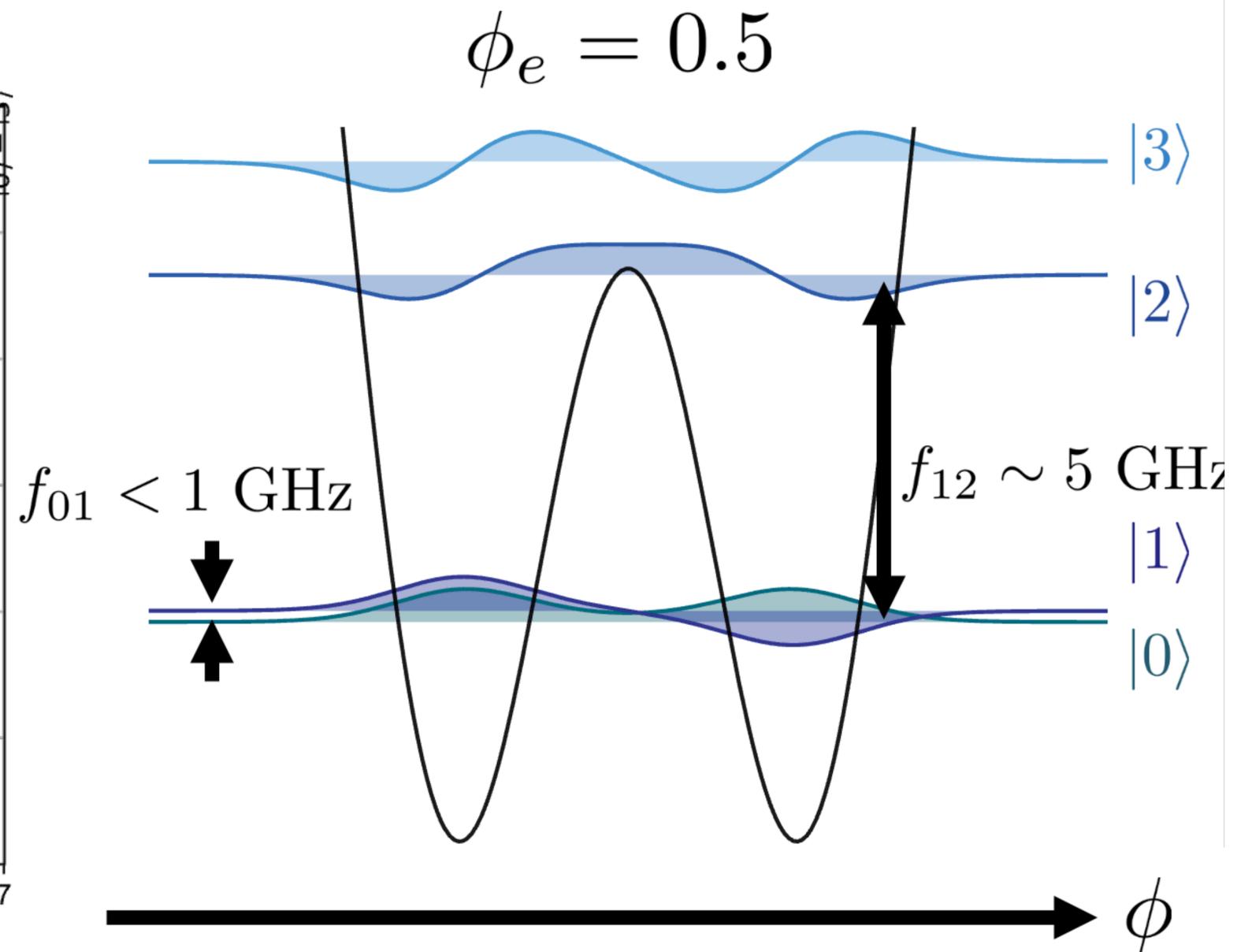


Qubit transition

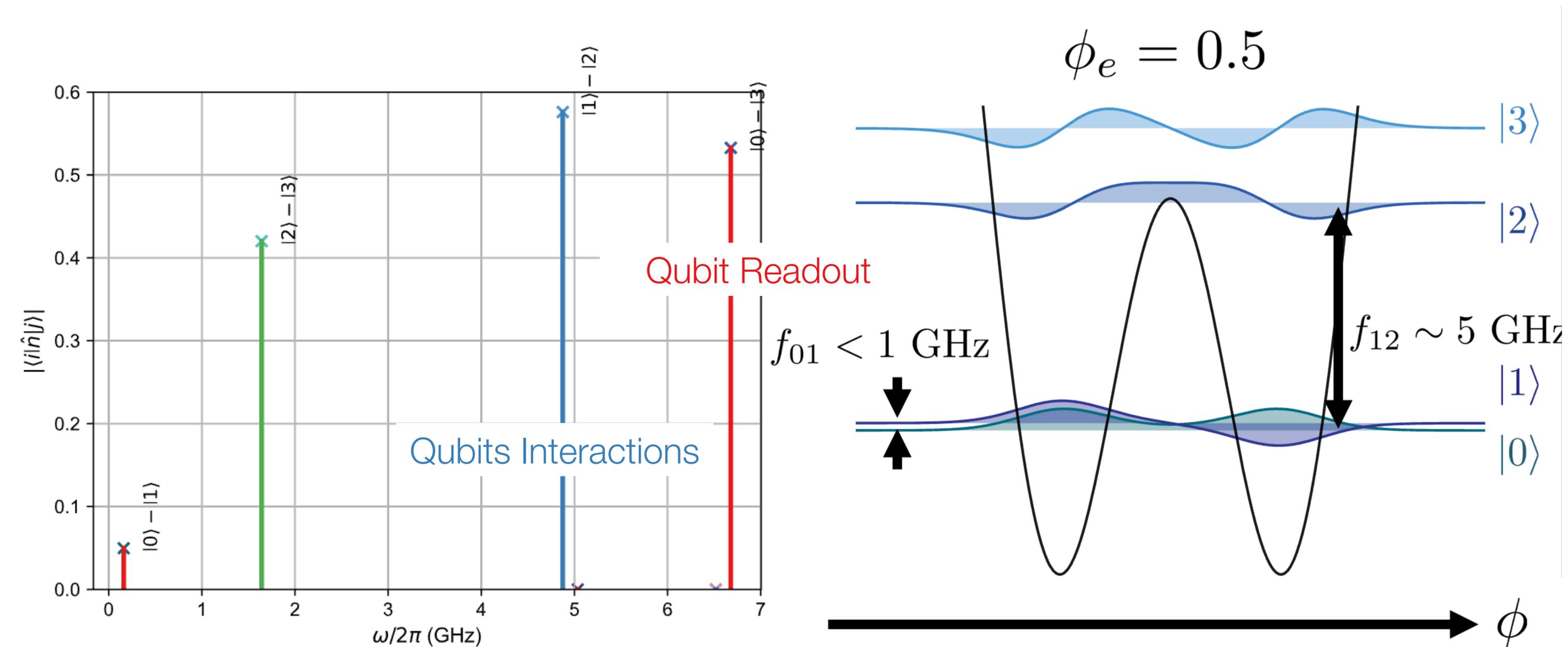
Fluxonium: standard parameters



Large anharmonicity



Fluxonium: standard parameters



Fluxonium: different flavours

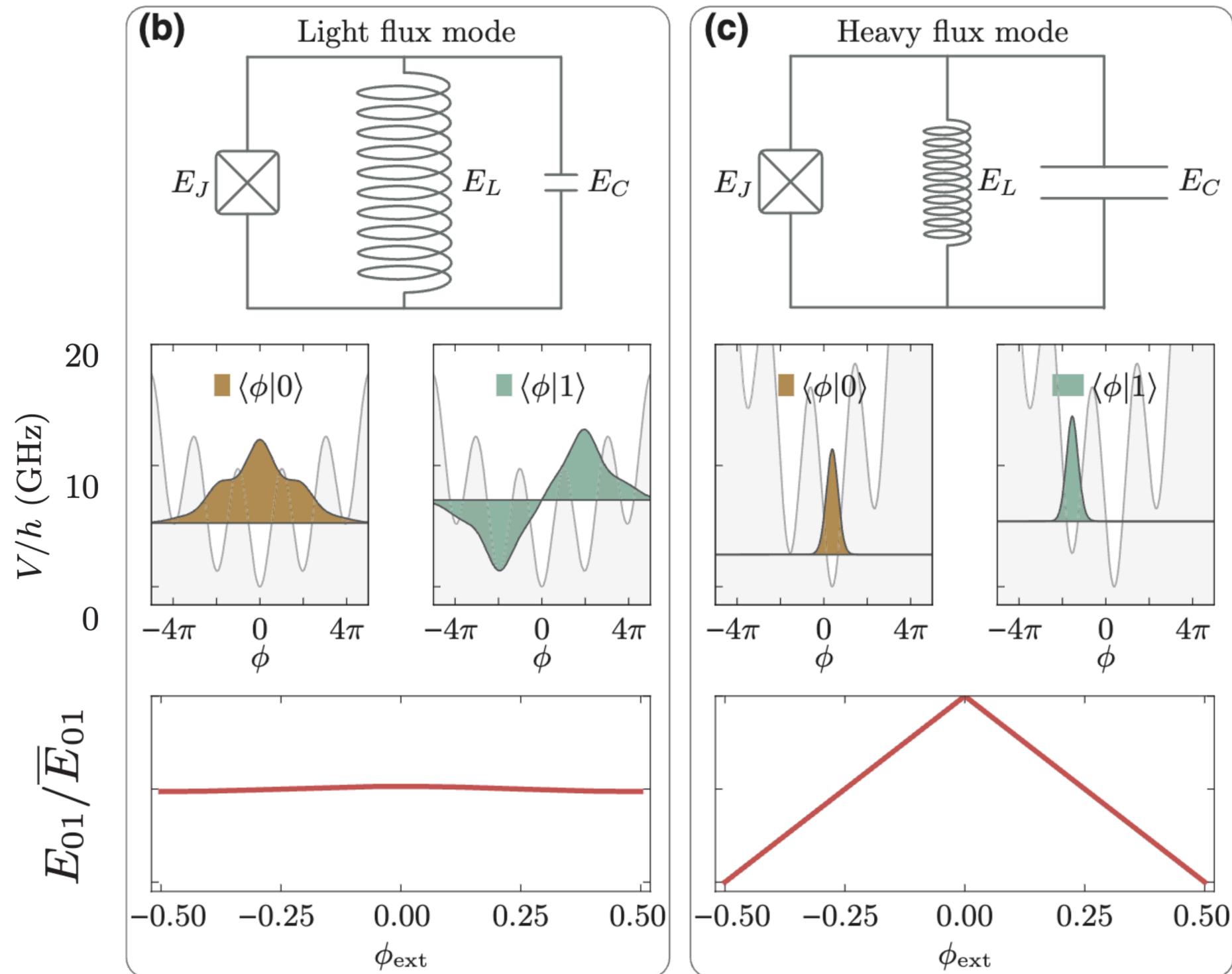
Light Fluxonium

$$E_J/E_C \ll 1$$

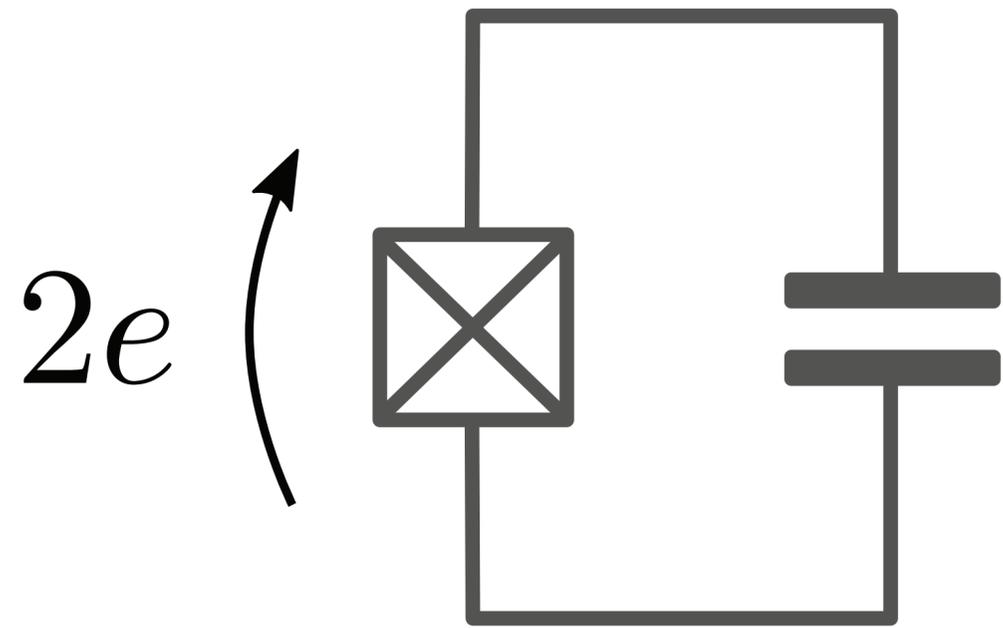
$$E_J/E_L \gg 1$$

Heavy Fluxonium

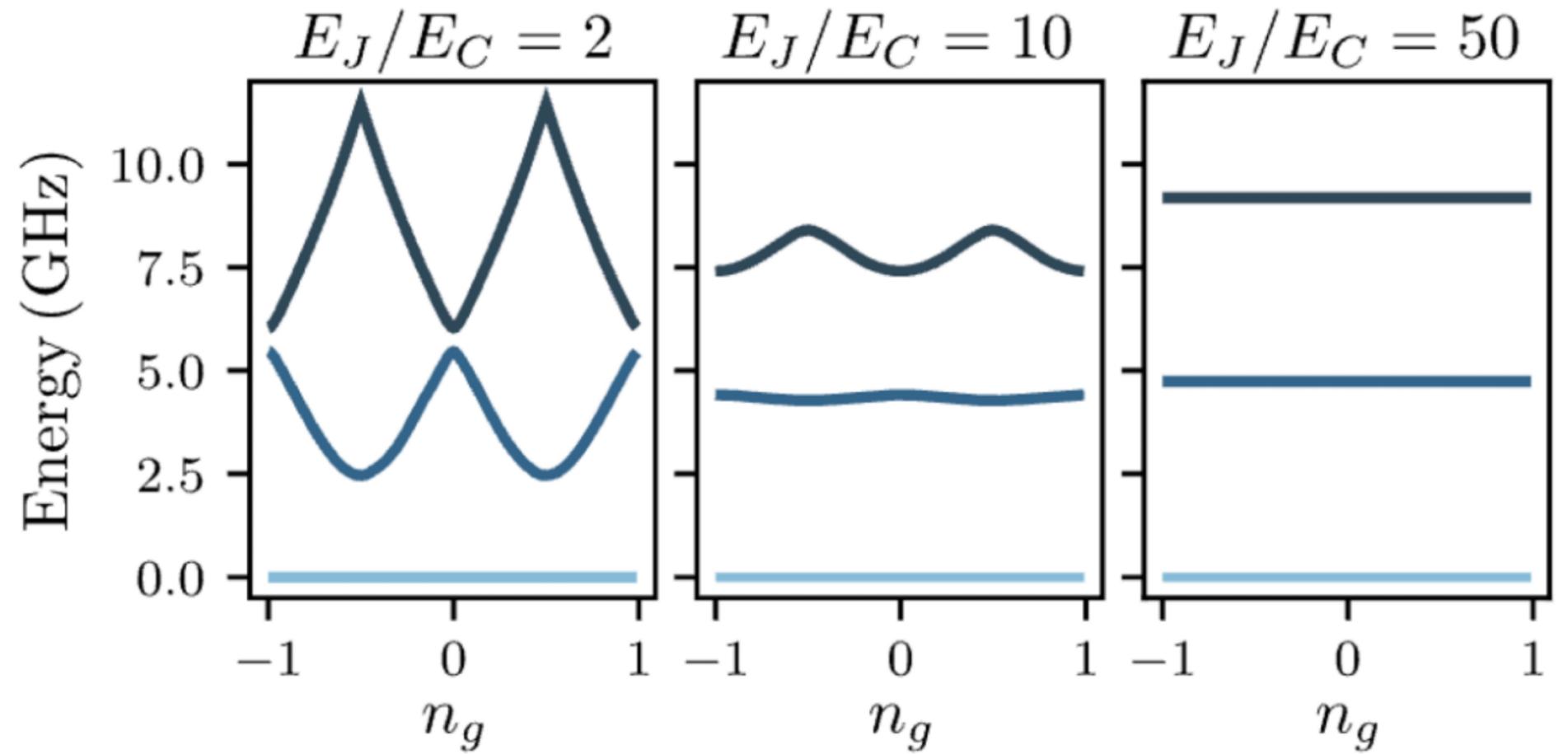
$$E_J/E_C \gg 1$$



Reducing dephasing (T_2 -protection): transmon case

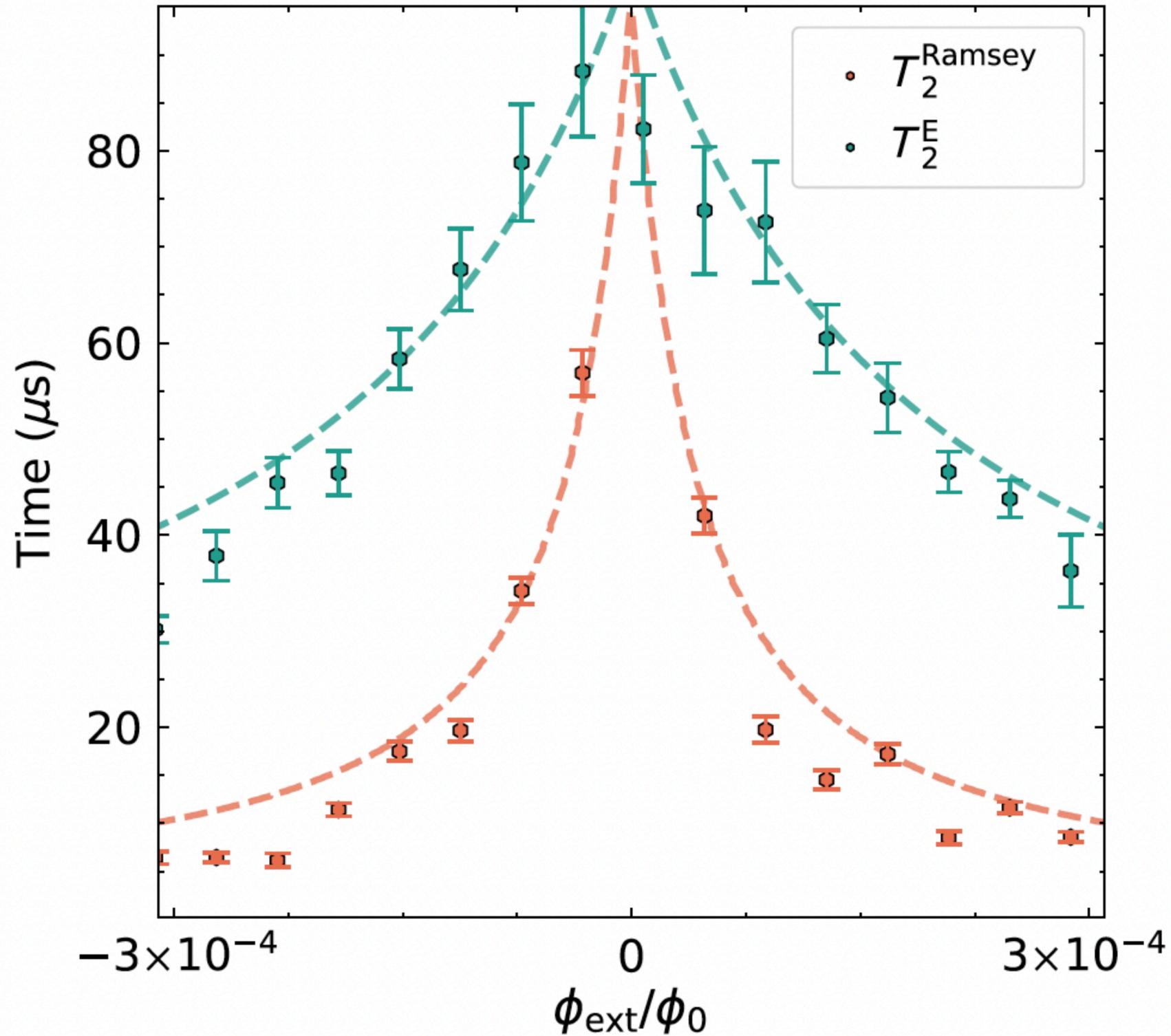


$$\hat{H}_T = 4E_C (\hat{n} - n_g)^2 - E_J \cos$$



Exponential protection against dephasing
(T_2 -protection)

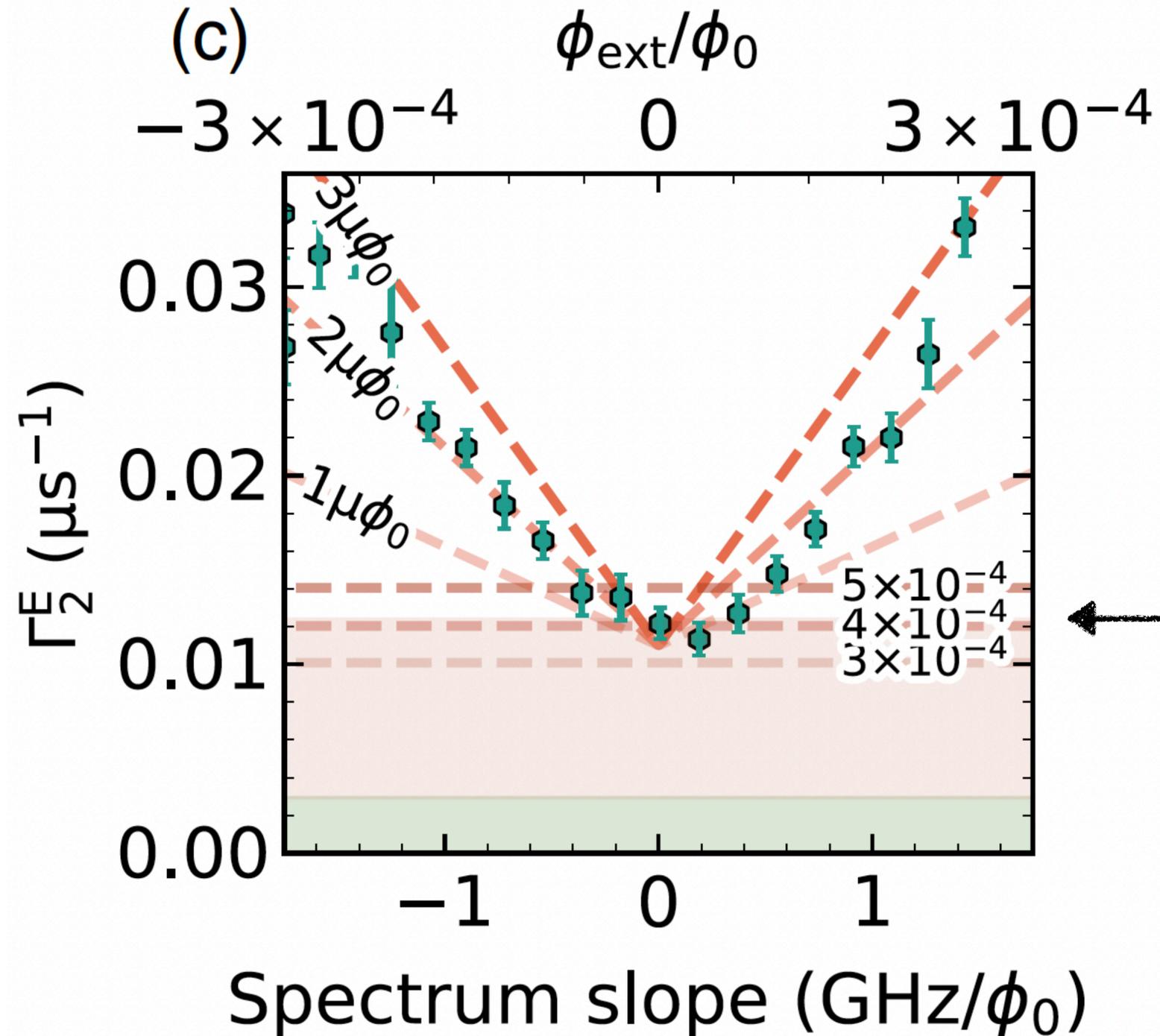
Dephasing in fluxonium qubits: flux noise



$$\Gamma_{\phi}^{\text{R}}(\Phi_{\text{ext}}) = \sqrt{A^{\text{R}} \ln\left(\frac{\Gamma_{\phi}^{\text{R}}(\Phi_{\text{ext}})}{2\pi f_{\text{IR}}}\right) \left|\frac{\partial\omega}{\partial\Phi_{\text{ext}}}\right|},$$

$$\Gamma_{\phi}^{\text{E}}(\Phi_{\text{ext}}) = \sqrt{A^{\text{E}} \ln(2) \left|\frac{\partial\omega}{\partial\Phi_{\text{ext}}}\right|},$$

Dephasing in fluxonium qubits: photon shot noise



$$\Gamma_{\phi}^{\text{th}} = \frac{\bar{n}_{\text{th}} \kappa \chi_{01}^2}{\kappa^2 + \chi_{01}^2}.$$

Reducing depolarisation (T₁-protection)

Fermi golden rule

$$1/T_1^\lambda \propto \left| \langle 0 | \hat{O} | 1 \rangle \right|^2 S_\lambda(\omega = E_{01}/\hbar)$$

Matrix element
(qubit design)



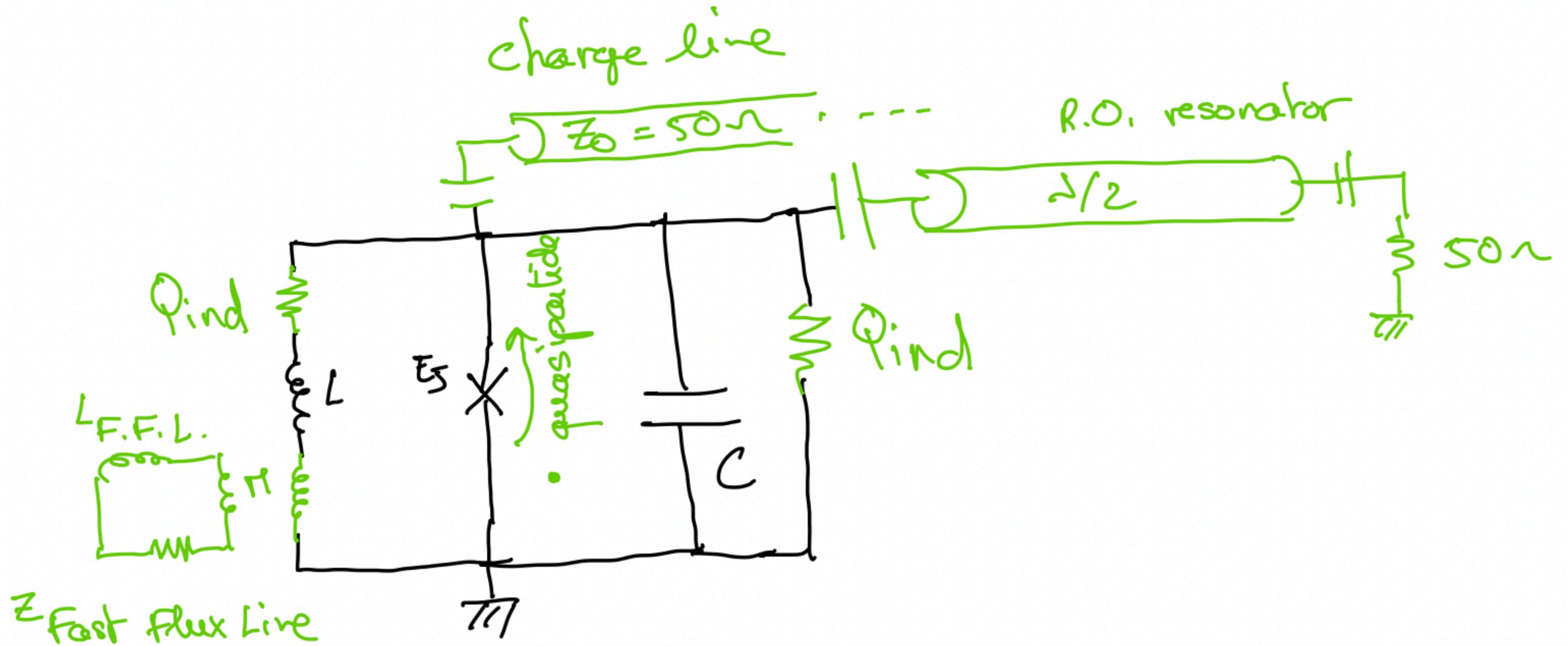
Noise PSD
(material, fab, environnement...)



λ : a given noise channel

\hat{O} : relevant operator for a given noise channel

Various depolarisation channels



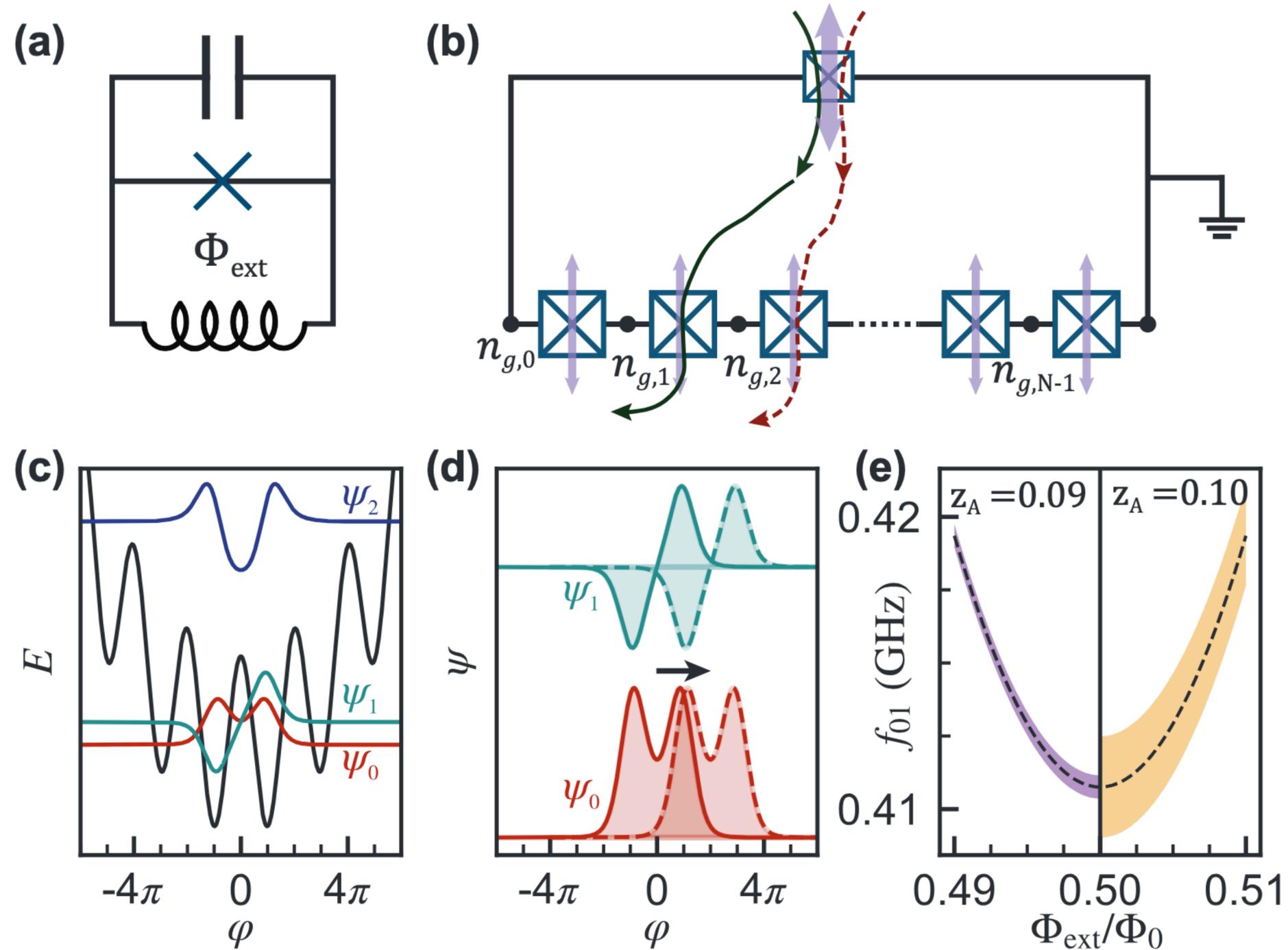
Various depolarisation channels

loss mechanism	$\langle 0 \hat{C} 1 \rangle$	$\text{Re} [Y_X(\omega_{01})]$	quality factor
capacitive	$\Phi_0 \langle 0 \hat{\varphi} 1 \rangle$	$\frac{\omega_{01} C}{Q_{cap}}$	$Q_{cap} > 3 \cdot 10^6$
inductive	$\Phi_0 \langle 0 \hat{\varphi} 1 \rangle$	$\frac{1}{\omega_{01} L Q_{ind}}$	$Q_{ind} > 500 \cdot 10^6$
quasiparticle	$\langle 0 \sin(\hat{\varphi}/2) 1 \rangle$	$\frac{G_t}{2Q_{qp}} \left(\frac{2\Delta}{\hbar\omega_{01}} \right)^{3/2}$	$Q_{qp} \approx x_{qp}^{-1} > 0.3 \cdot 10^6$
radiative (Purcell)	$\Phi_0 \langle 0 \hat{\varphi} 1 \rangle$	HFSS numerical simulations	$Q_{out} = 2000$

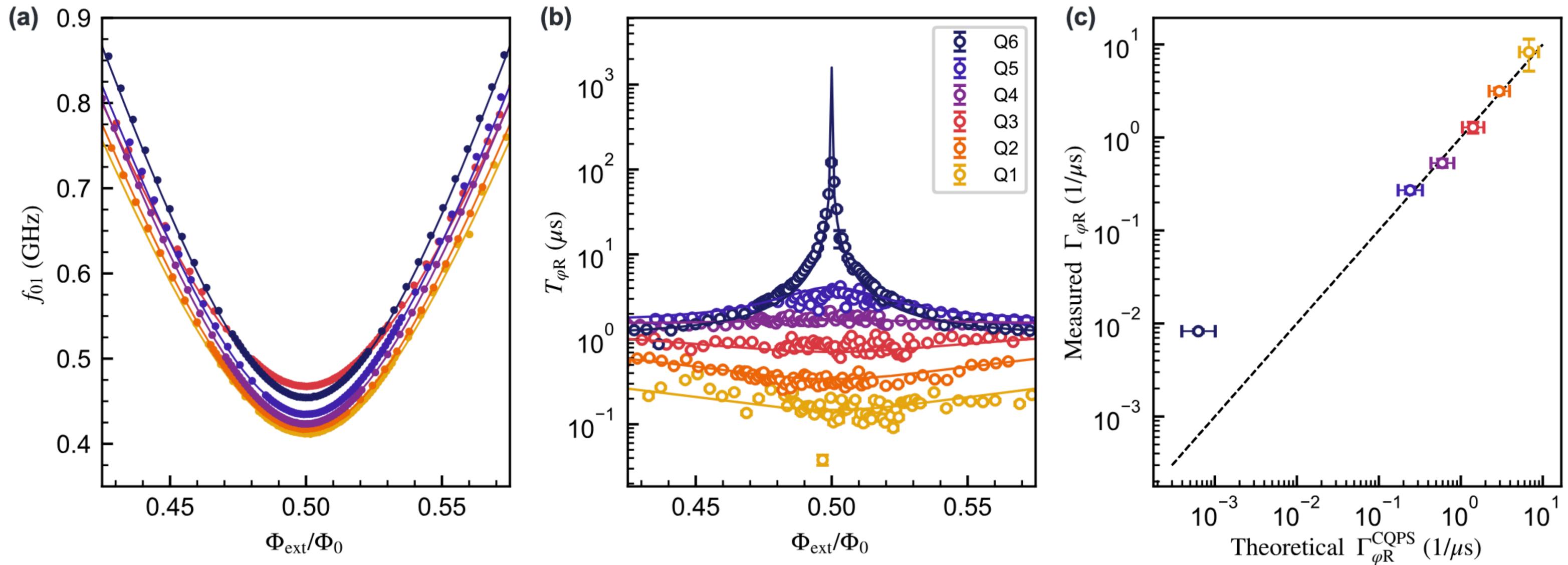
Table from Pop et al. Nature (2014)

See also: Nguyen et al. Phys. Rev. X (2019)
Smith et al. npj Quant. Inf. (2020)

Bonus track: dephasing caused by QPS in the superinductance



Bonus track: dephasing caused by QPS in the superinductance



Take home message $E_J/E_C > 60$ (In the superinductance)