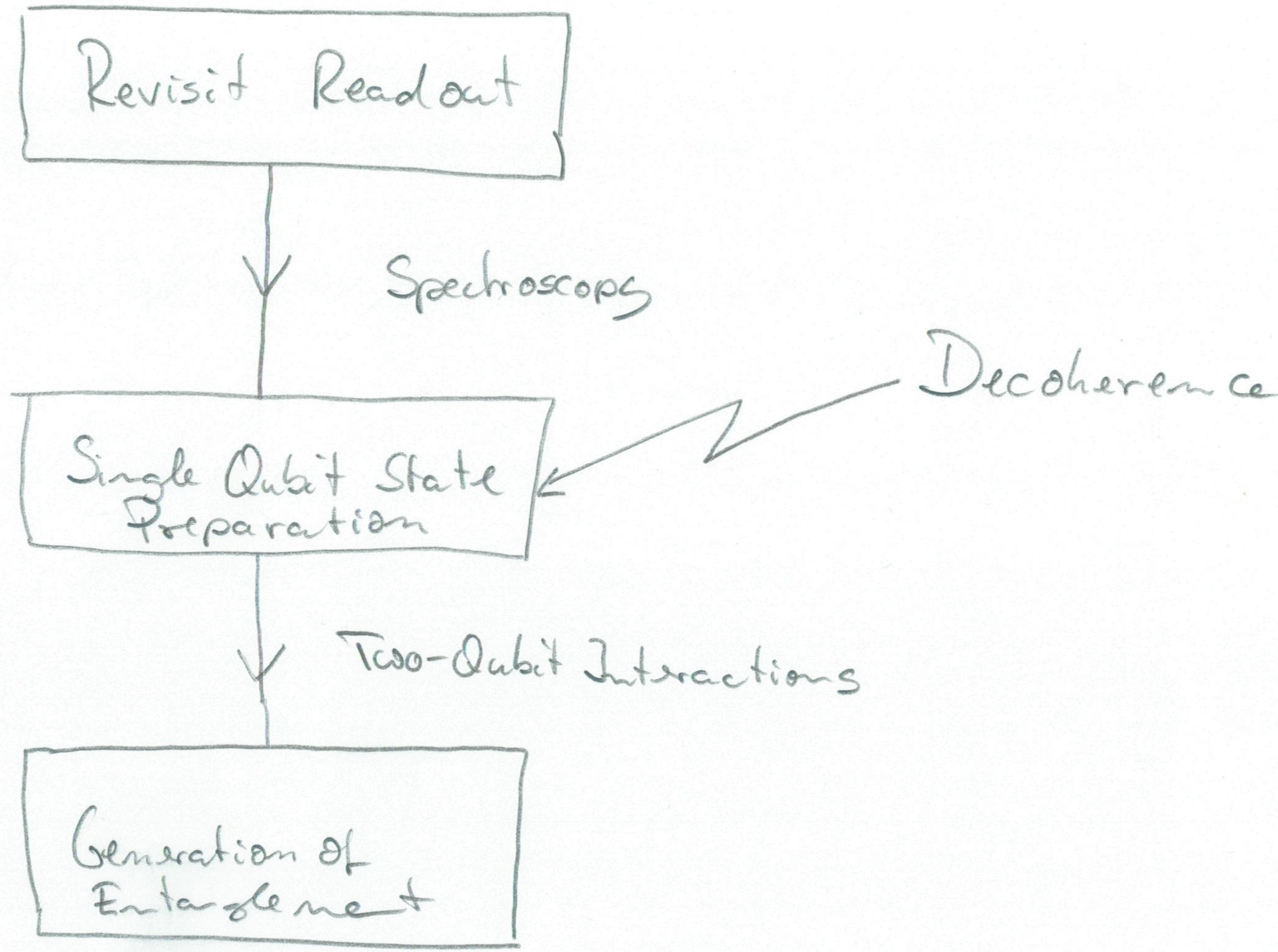
# QIPC with Superconducting Circuits



Before: linear oscillators, non-linear qubits, qubit oscillator interaction (Cavity QED), read out

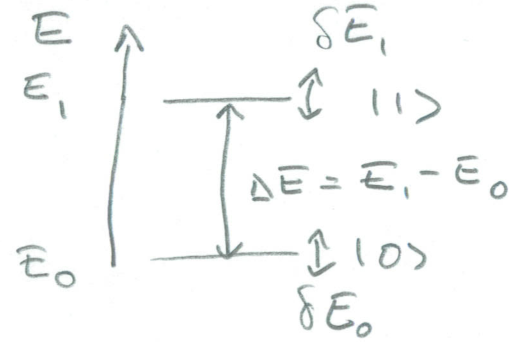
Today:




Next Monday: CNOT gate, Realization of algorithms

# Sources of Decoherence

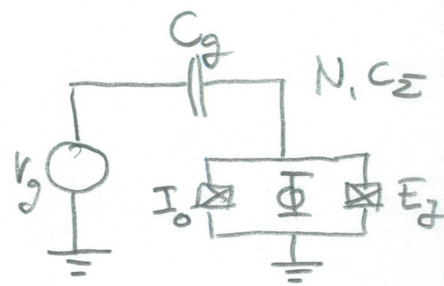





- Consider specific qubit: Cooper pair box

$$\hat{H}_0 = E_C(\hat{N} - N_g)^2 + E_J \cos\hat{\delta}$$

- parameters $\lambda_i$ of $\hat{H}_0$




$$\lambda_i : \begin{cases} E_C = \dfrac{(2e)^2}{C_\Sigma} \; ; \; N_g = \dfrac{C_g V_g}{2e} & \text{electrostatic energy} \\[2ex] E_J = \dfrac{I_0 \Phi_0}{2\pi} \; ; \; \delta = \pi \dfrac{\Phi}{\Phi_0} & \text{magnetic energy} \end{cases}$$

- fluctuations $\delta\lambda_i$ in $\lambda_i$ lead to trasition energy fluctuations

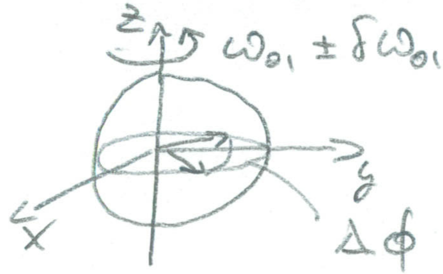
$$\hat{H} = H_0 \hat{\sigma}_z$$

$$\hat{H} = \left( H_0(\lambda_0) + \frac{\partial H_0}{\partial \lambda} \delta\lambda + \frac{\partial^2 H_0}{\partial \lambda^2} \delta\lambda^2 + \dots \right) \hat{\sigma}_z$$

$\delta\lambda$ : deviation from desired parameter $\lambda_0$

- deviation $\Delta\phi$ of phase from desired value $\phi_0$ after time $t$

$$\Delta\phi = \frac{\partial\omega_{01}}{\partial\lambda}\int_0^t \delta\lambda(t')\,dt'$$




- avoiding fluctuations $\Delta\phi$

  - $\delta\lambda = 0$ — avoid fluctuations in parameter

  - $\frac{\partial H_0}{\partial\lambda} = 0$ — avoid sensitivity of Hamiltonian to parameter

  - spin echo — dynamic cancellation of the effect of slow fluctuations

# Generating Entanglement using Sideband Transitions



- consider qubit A, qubit B, resonator R $\quad |A, B, R\rangle$

$$|gg0\rangle \xrightarrow{\pi_A} |eg0\rangle$$

$$\xrightarrow{(\pi/2)^+_B} \frac{1}{\sqrt{2}}\left(|eg0\rangle + |ee1\rangle\right)$$

$$\xrightarrow{(\pi)^+_A} \frac{1}{\sqrt{2}}\left(|eg\rangle + |ge\rangle\right) \otimes |0\rangle = \Psi^+ \otimes |0\rangle \quad \text{Bell state}$$

$$\xrightarrow{\pi_B} \frac{1}{\sqrt{2}}\left(|gg\rangle + |ee\rangle\right) \otimes |0\rangle = \Phi^+ \otimes |0\rangle \quad \text{Bell state}$$

- note: any interaction that can generate entanglement can be used to realize a logic gate