

# Evaluation of gate designs

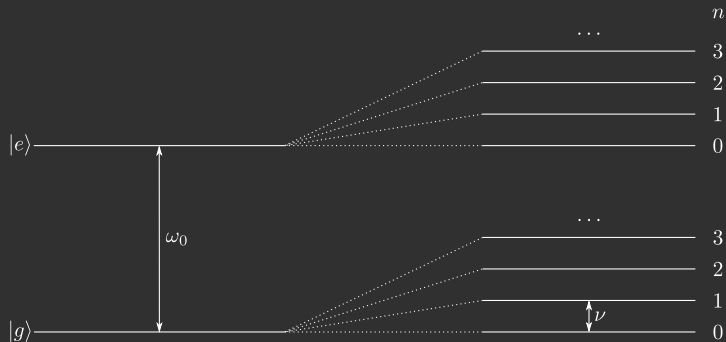
## For trapped ion quantum computers

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Imperial College London

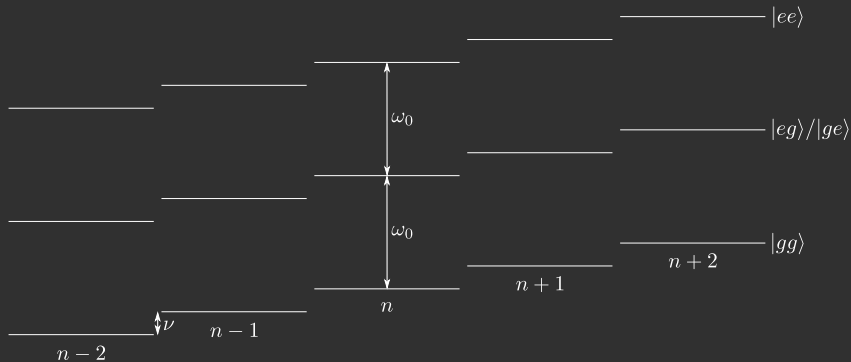
March, 2022

# Energy structure



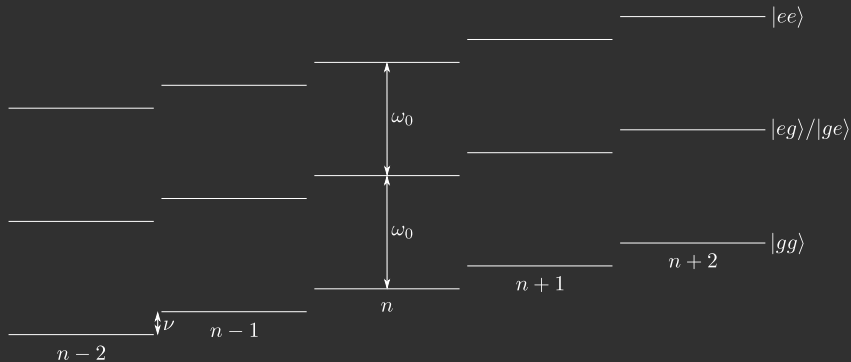
$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{\sigma}_z + \hbar\nu\left(\hat{a}^\dagger\hat{a} + \frac{1}{2}\right)$$

# Energy structure



$$\hat{H} = -\frac{\hbar\omega_0}{2} \sum_i^n \hat{\sigma}_z^{(i)} + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right)$$

# Energy structure



$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu\left(\hat{a}^\dagger\hat{a} + \frac{1}{2}\right)$$

# Driving the system

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\mathbf{kz} - \omega_l t)} + h.c.$$

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{a} + \hat{a}^\dagger) - \omega_l t)} + h.c.$$

$$\hat{H}_I = \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{a} + \hat{a}^\dagger) - \Delta_l t)} + h.c.$$

$$\eta = \mathbf{kz}_0$$

$$\hat{\hat{a}} = \hat{a} e^{-i\nu t}$$

$$\hat{\hat{a}}^\dagger = \hat{a}^\dagger e^{i\nu t}$$

# Driving the system

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\mathbf{kz} - \omega_l t)} + h.c.$$

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{a} + \hat{a}^\dagger) - \omega_l t)} + h.c.$$

$$\hat{H}_I = \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{\tilde{a}} + \hat{\tilde{a}}^\dagger) - \Delta_l t)} + h.c.$$

$$\eta = \mathbf{kz}_0$$

$$\hat{\tilde{a}} = \hat{a} e^{-i\nu t}$$

$$\hat{\tilde{a}}^\dagger = \hat{a}^\dagger e^{i\nu t}$$

# Driving the system

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\mathbf{kz} - \omega_l t)} + h.c.$$

$$\hat{H} = -\frac{\hbar\omega_0}{2}\hat{S}_z + \hbar\nu \left( \hat{a}^\dagger \hat{a} + \frac{1}{2} \right) + \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{a} + \hat{a}^\dagger) - \omega_l t)} + h.c.$$

$$\hat{H}_I = \sum_l \frac{\Omega_l}{2} \hat{S}_+ e^{-i(\eta(\hat{\tilde{a}} + \hat{\tilde{a}}^\dagger) - \Delta_l t)} + h.c.$$

$$\eta = \mathbf{kz}_0$$

$$\hat{\tilde{a}} = \hat{a} e^{-i\nu t}$$

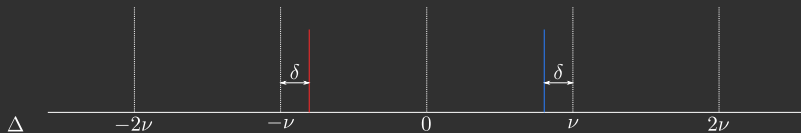
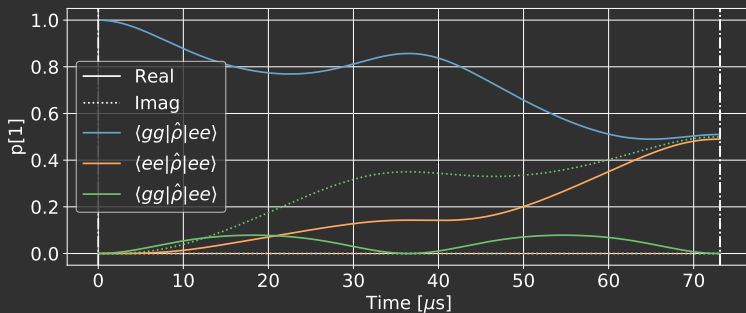
$$\hat{\tilde{a}}^\dagger = \hat{a}^\dagger e^{i\nu t}$$

# Approximations

$$\frac{d\hat{\rho}}{dt} = -\frac{i}{\hbar}[\hat{H}, \hat{\rho}]$$

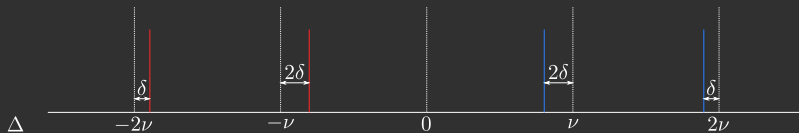
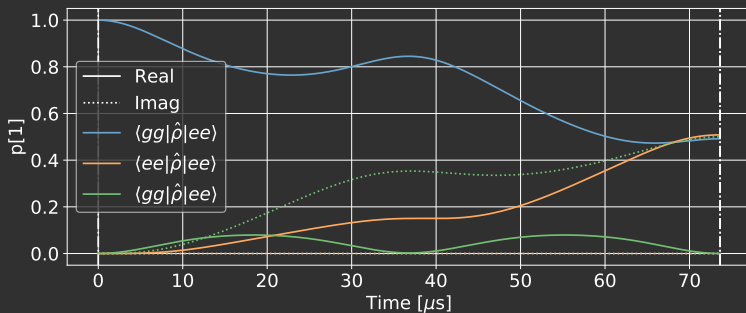


# Mølmer-Sørensen gate<sup>1</sup>



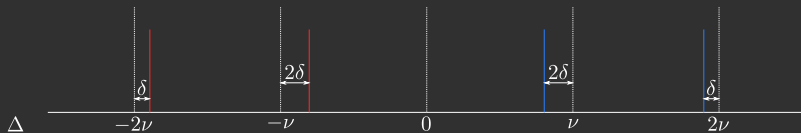
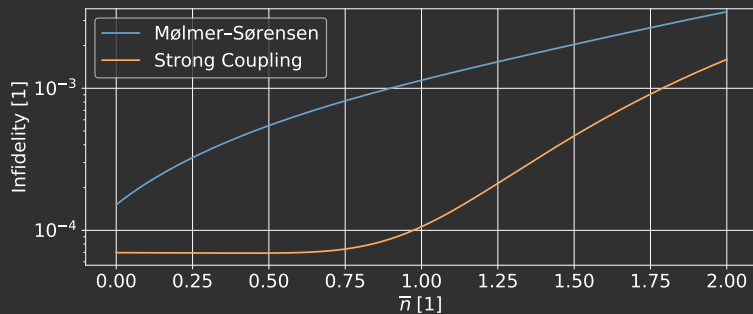
<sup>1</sup>A. Sørensen and K. Mølmer, "Entanglement and quantum computation with ions in thermal motion," , 2000.

# Strong coupling gate<sup>2</sup>



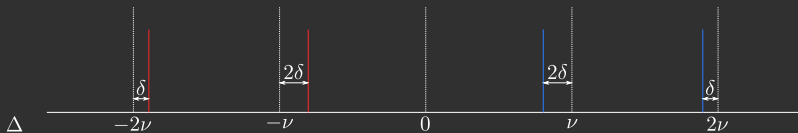
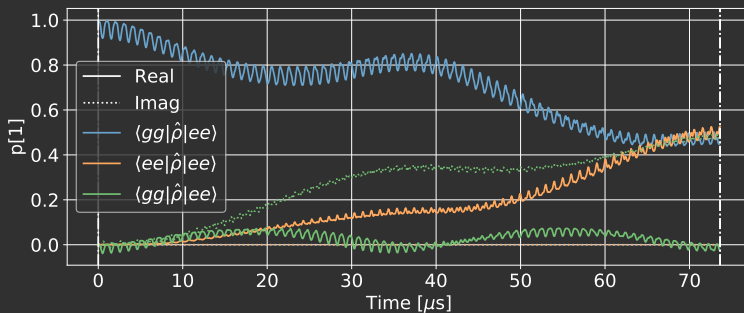
<sup>2</sup>M. Sameti, J. Lishman, and F. Mintert, "Strong-coupling quantum logic of trapped ions," 2021.

# Strong coupling gate<sup>2</sup>



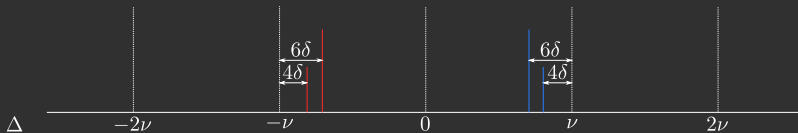
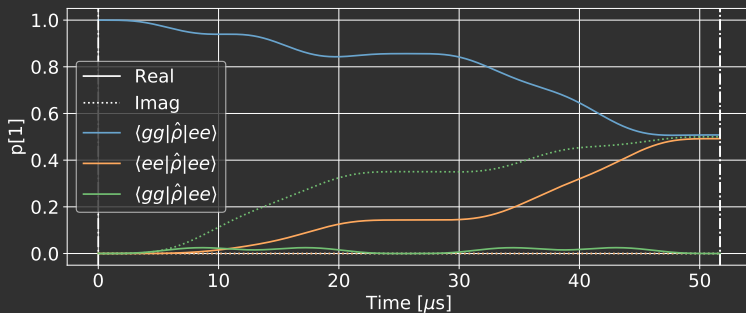
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# Strong coupling gate<sup>2</sup>



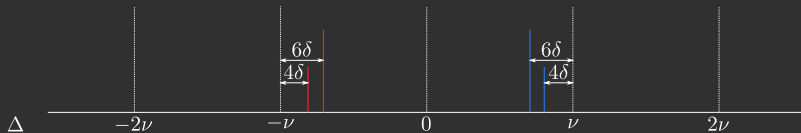
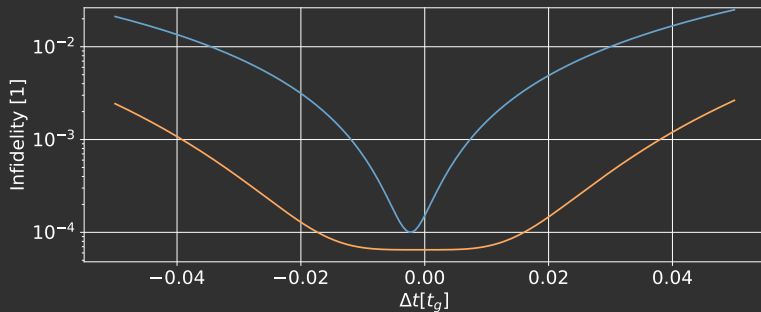
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# Cardioid gate<sup>3</sup>



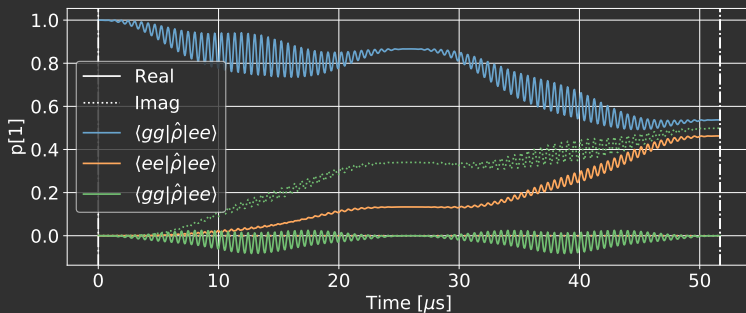
<sup>3</sup>Y. Shapira, R. Shaniv, T. Manovitz, *et al.*, "Robust entanglement gates for trapped-ion qubits," 2018.

# Cardioid gate<sup>3</sup>



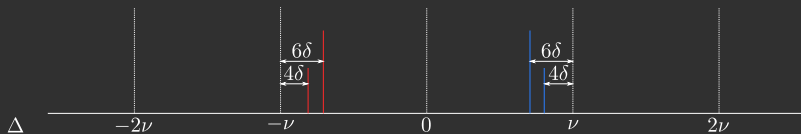
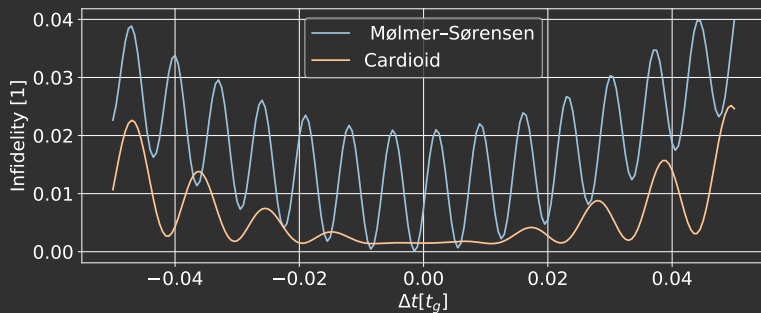
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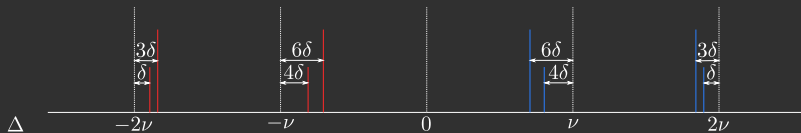
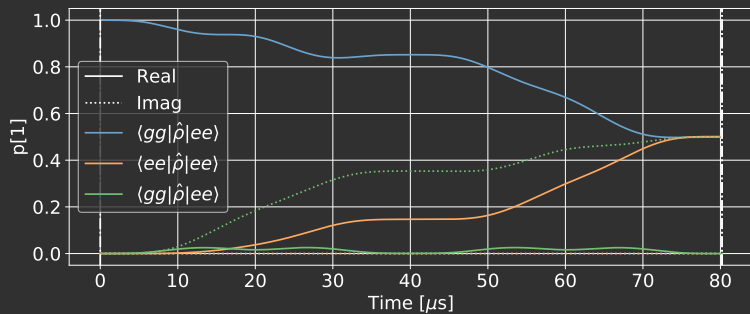
# Cardioid gate<sup>3</sup>



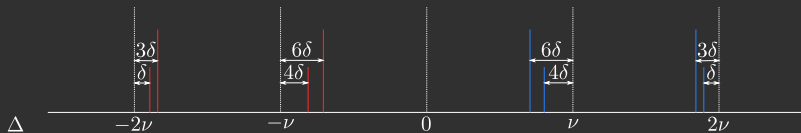
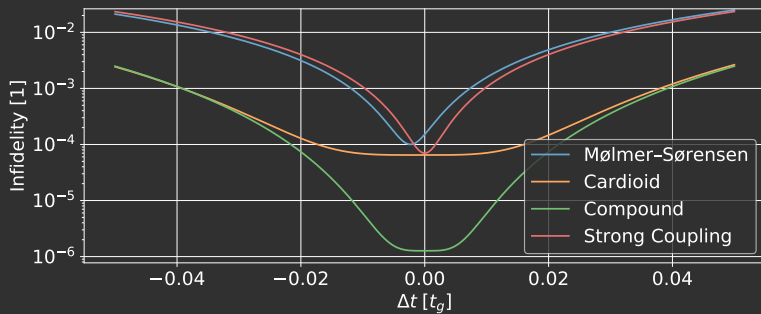
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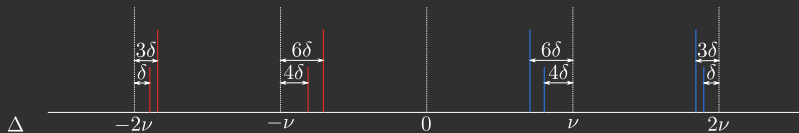
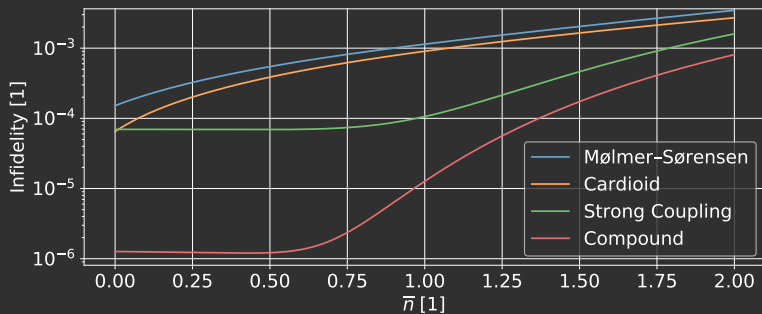
# Compound gate



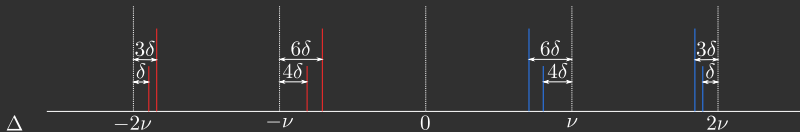
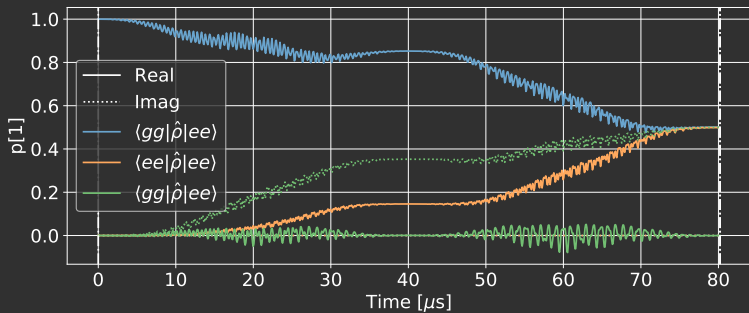
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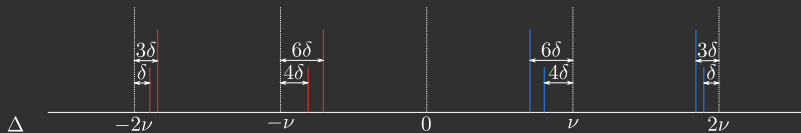
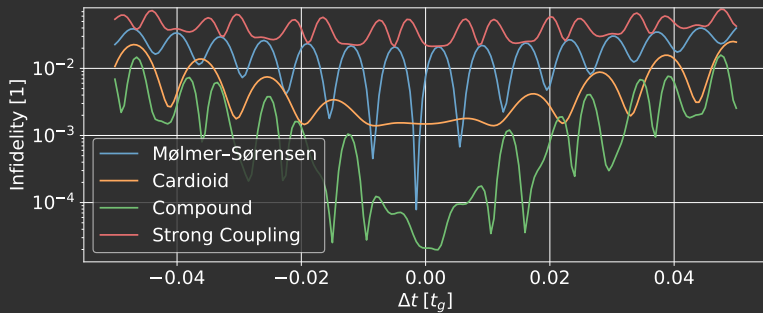
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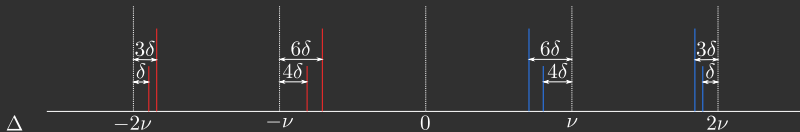
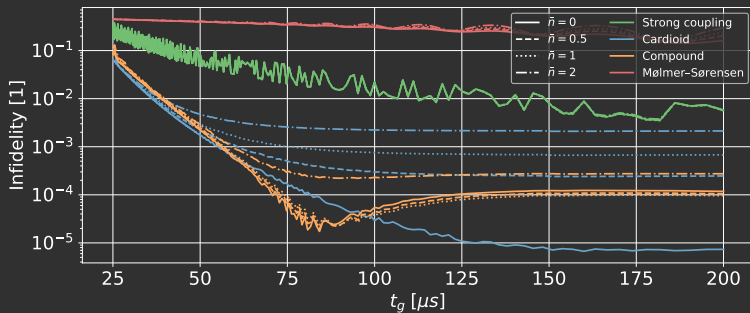
# Compound gate



# Compound gate



# Compound gate



# The End