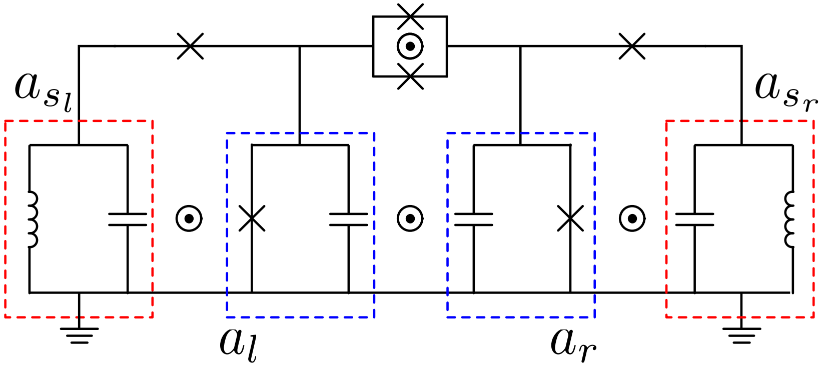
Direct Measurement of a Very Small Logical Qubit's Observables

Nick Materise, Eliot Kapit

Colorado School of Mines, Golden, CO 80401

Very Small Logical Qubit (VSLQ) – Introduction



E. Kapit, PRL **116**, 150501 (2016)

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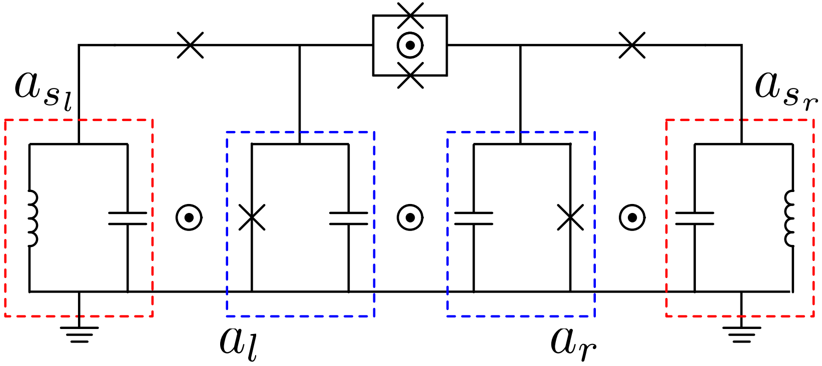

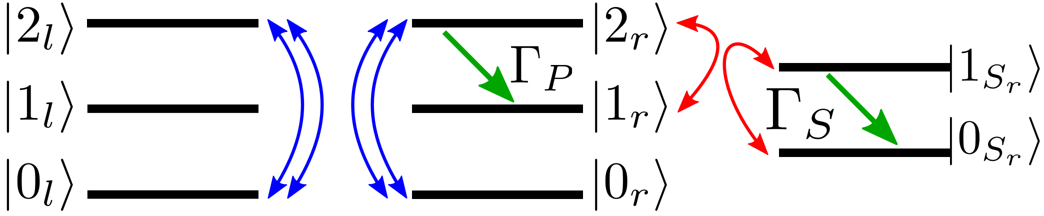

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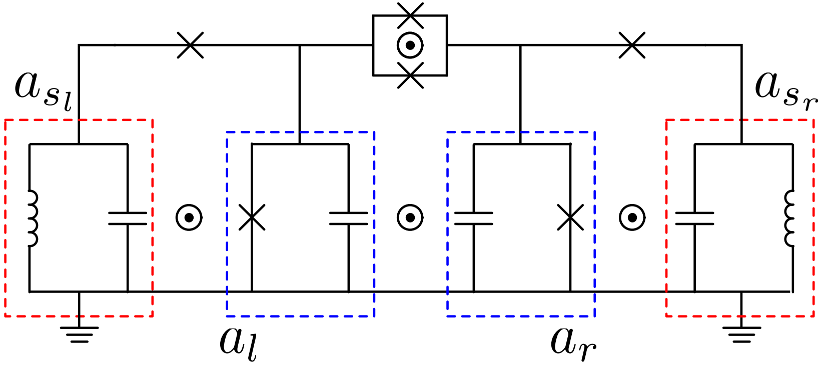

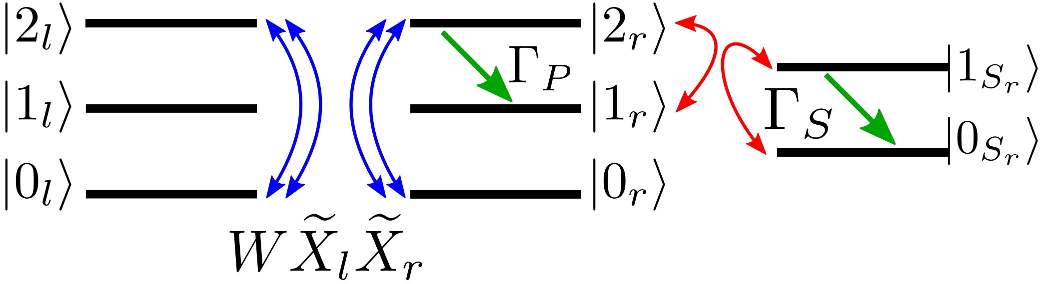

$$\widetilde{X}_k = \frac{1}{\sqrt{2}}\left(a_k^{\dagger 2} + a_k^2\right)$$

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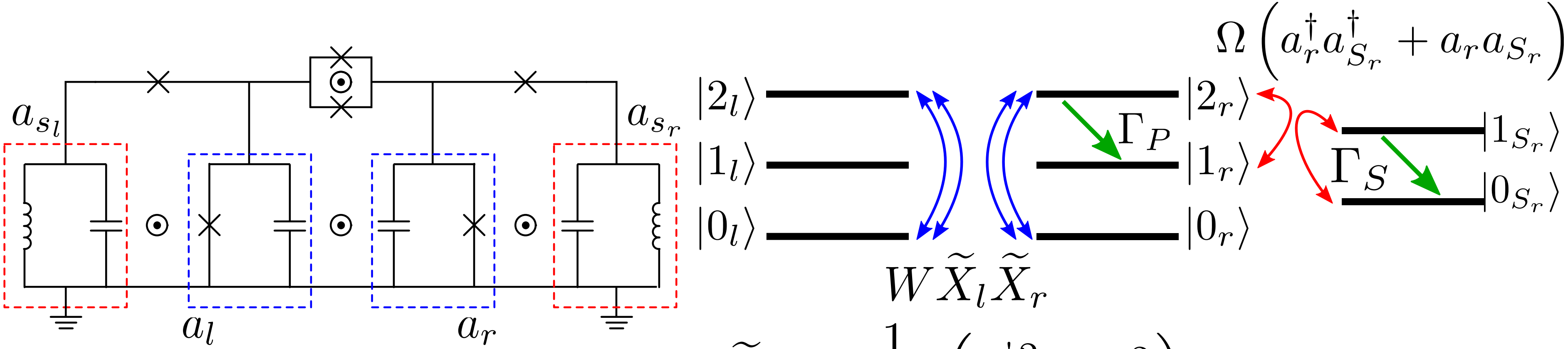

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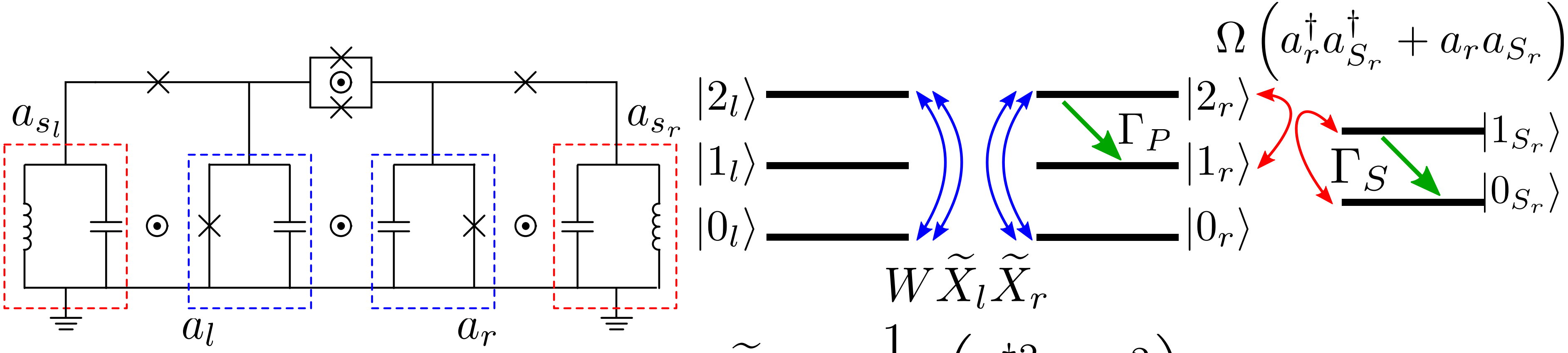

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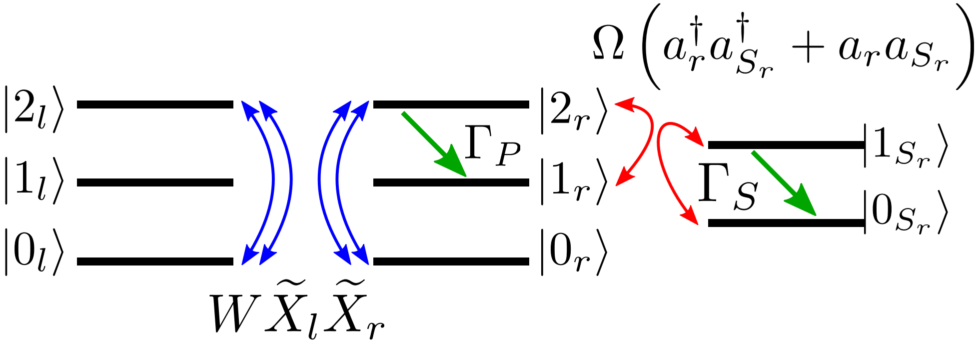
A29.00012
A29.00013
A42.00013
H62.00002

Very Small Logical Qubit (VSLQ) – Hamiltonian

$$H_P = -W\widetilde{X}_l\widetilde{X}_r + \frac{\delta}{2}\left(P_l^1 + P_r^1\right) \qquad P_k^n = |n_k\rangle\langle n_k|$$



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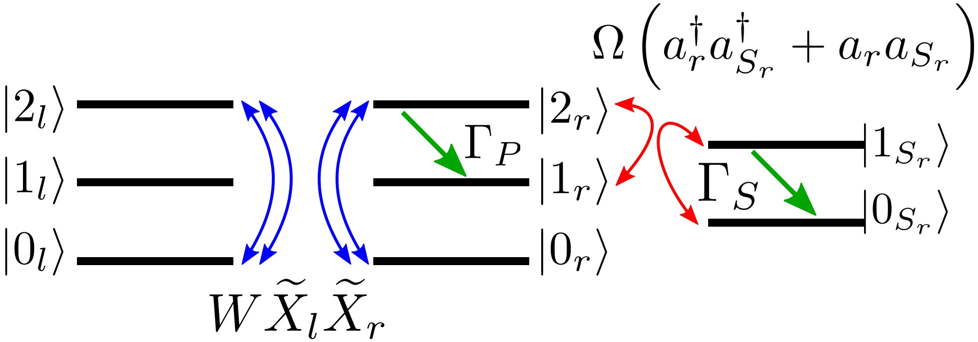

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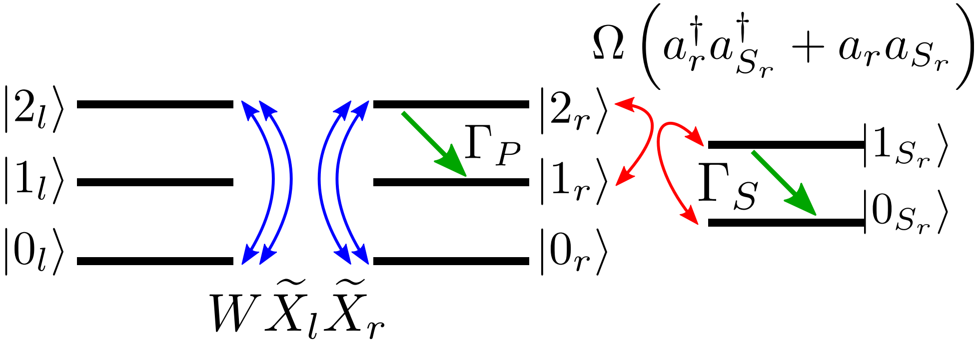
$$H_{PS} = \Omega\left(a_l^\dagger a_{S_l}^\dagger + a_r^\dagger a_{S_r}^\dagger + \text{h.c.}\right)$$



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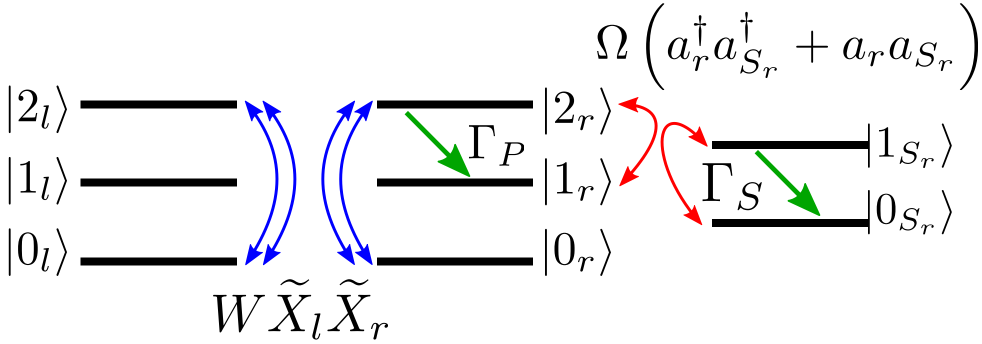
$$H = H_P + H_S + H_{PS}$$



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Direct Measurement

$$H_{\text{disp}} = \omega_c a^\dagger a + \frac{1}{2}\omega_q \sigma_z + \chi a^\dagger a \sigma_z$$

N. Didier et. al, PRL **115**, 203601 (2015)

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$$+ \left[g_z(t) a^\dagger + g_z^*(t) a\right] \sigma_z$$

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$$g_z(t) = |\widetilde{g}_z| \cos\left(\omega_c t + \varphi\right)$$

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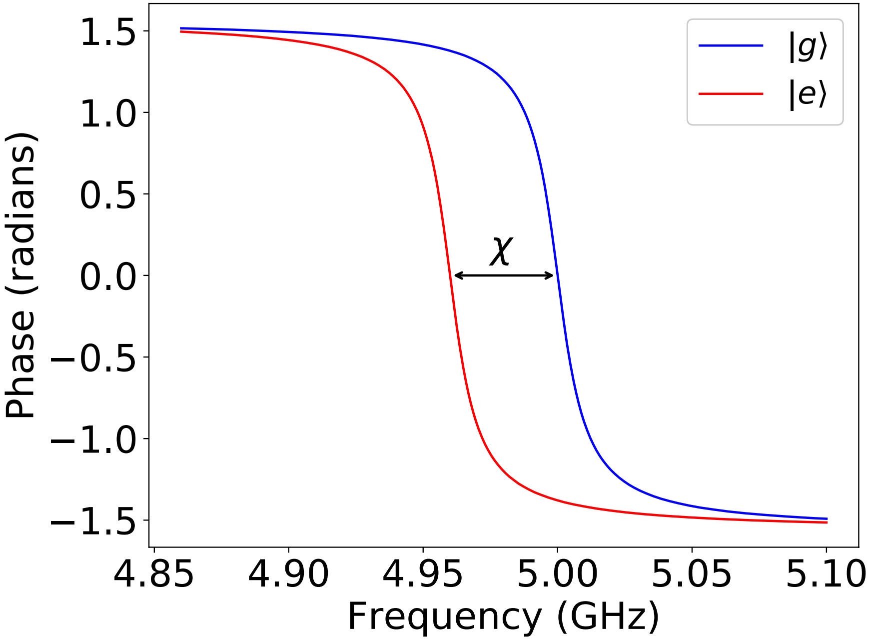
Typical Dispersive Readout
Cavity Phase Response



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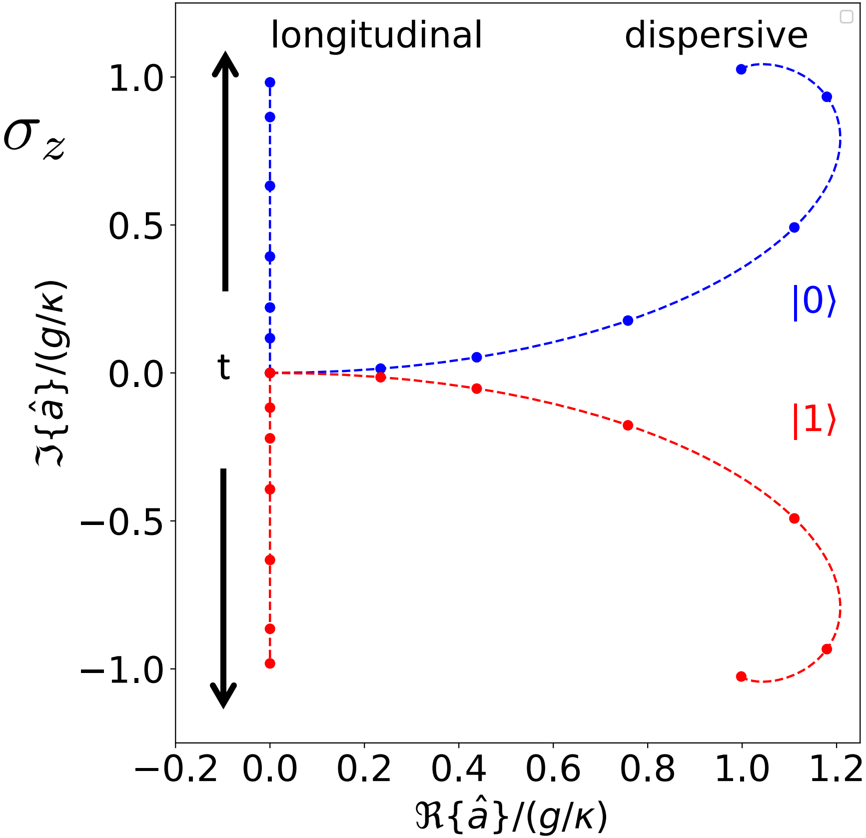
Readout Phase Diagram



Direct Measurement – Applied to the VSLQ

Single mode readout, interaction picture

$$H_{PC} = g\left(a_c + a_c^{\dagger}\right)\left(\widetilde{X}_l + \widetilde{X}_r\right), \quad \widetilde{X}_l \widetilde{X}_r = 1$$

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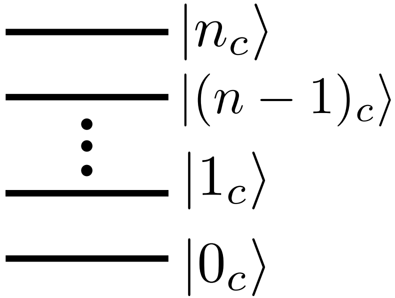

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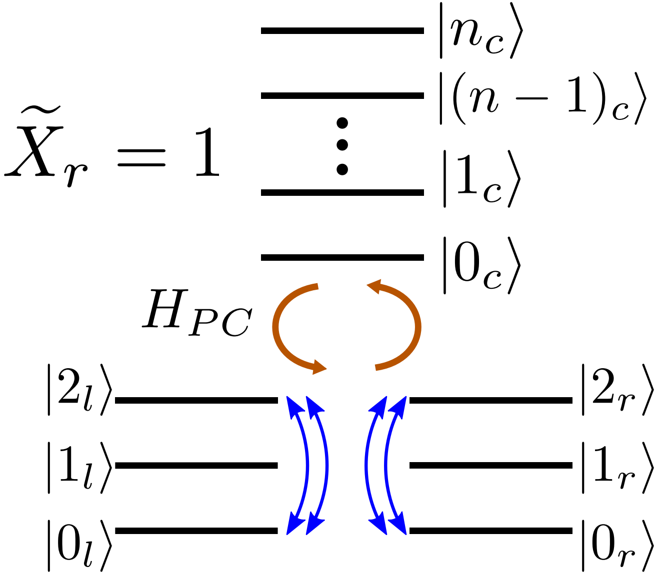

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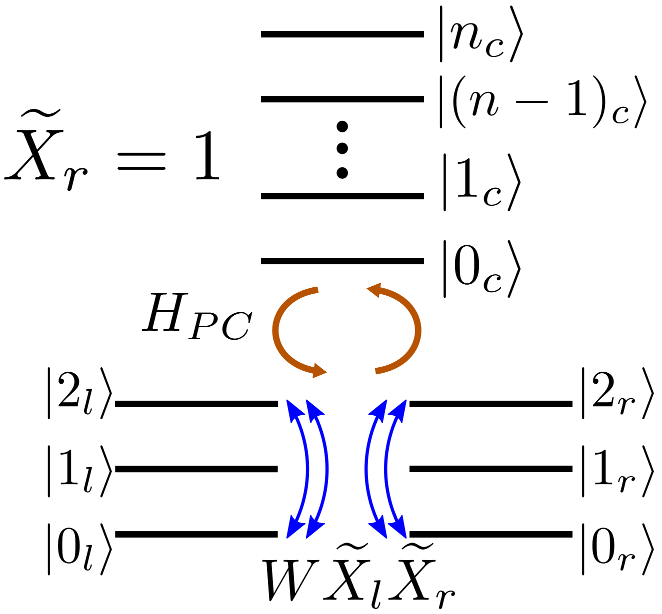

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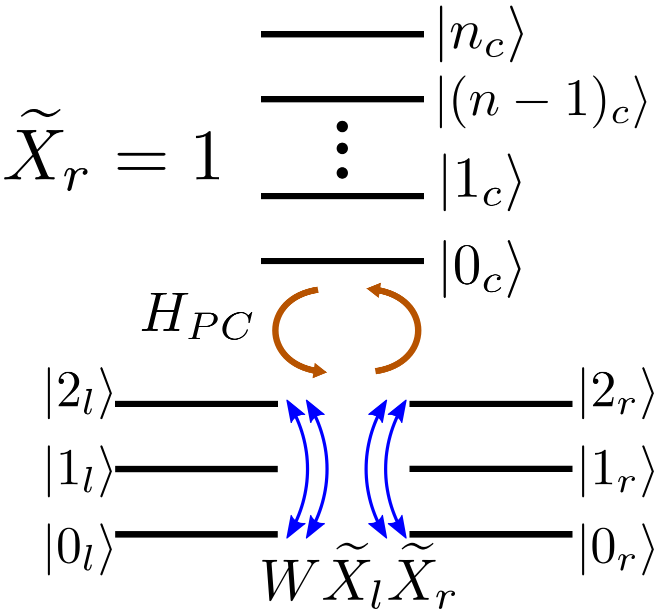
1. Show good contrast between logical states



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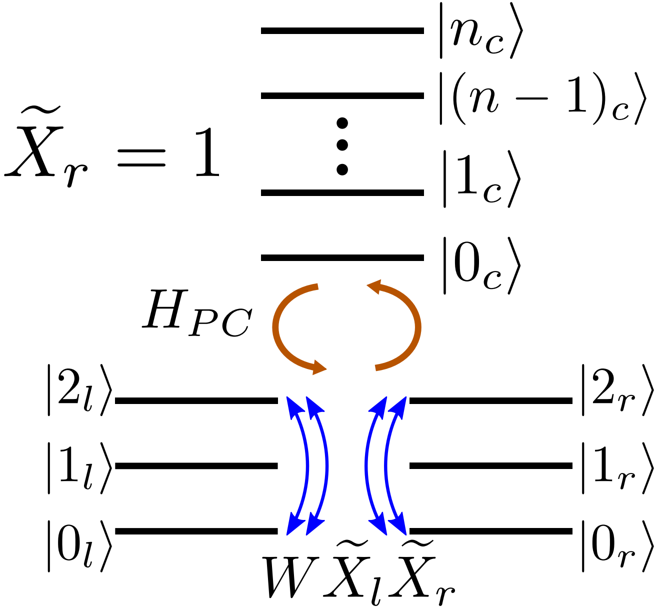
1. Show good contrast between logical states
2. Distinguish logical from error states



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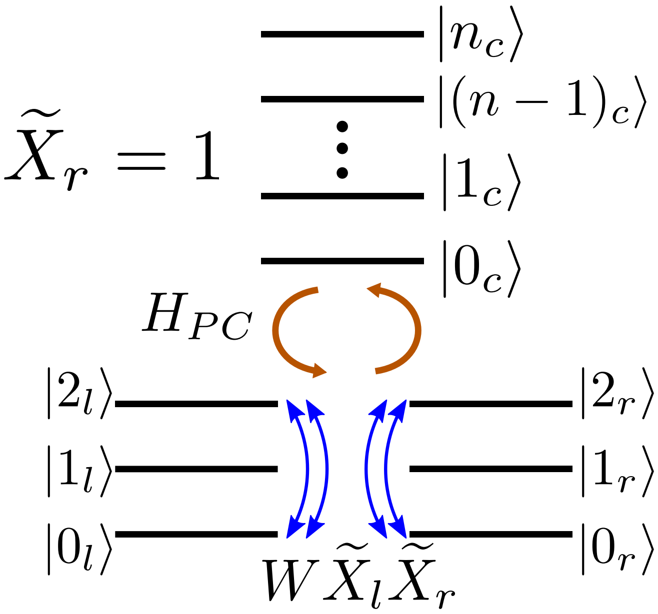
1. Show good contrast between logical states
2. Distinguish logical from error states
3. Quantify leakage outside the logical manifold



$$\widetilde{X}_k = \frac{1}{\sqrt{2}}\left(a_k^{\dagger 2} + a_k^2\right)$$

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Results – Logical States Separable?

$$|L_0\rangle = \frac{|2_l\rangle + |0_l\rangle}{\sqrt{2}} \frac{|2_r\rangle + |0_r\rangle}{\sqrt{2}} |0_{S_l}\rangle |0_{S_r}\rangle$$

$$|L_1\rangle = \frac{|2_l\rangle - |0_l\rangle}{\sqrt{2}} \frac{|2_r\rangle - |0_r\rangle}{\sqrt{2}} |0_{S_l}\rangle |0_{S_r}\rangle$$

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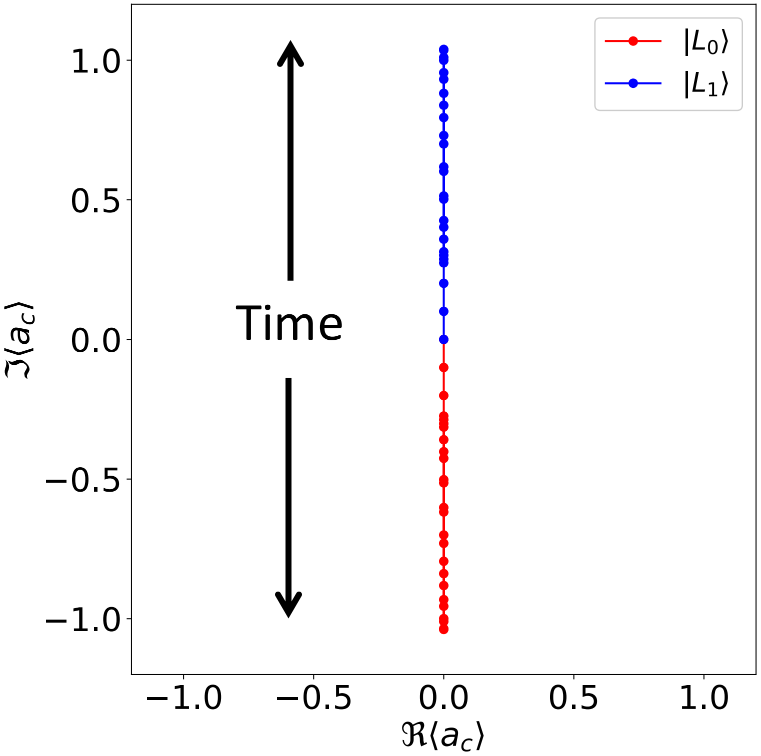

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Time slices equally spaced from t = 0 to t = 1.4 μs

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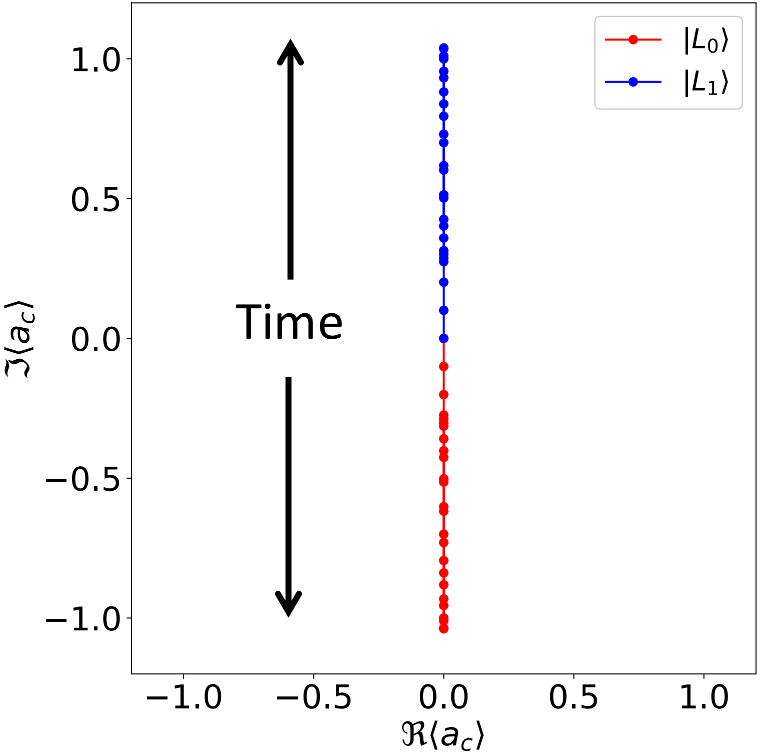

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$$\delta/2\pi = 350 \text{ MHz}$$

$$W/2\pi = 35 \text{ MHz}$$
$$\Omega = 0$$

Time slices equally spaced from t = 0 to t = 1.4 μs

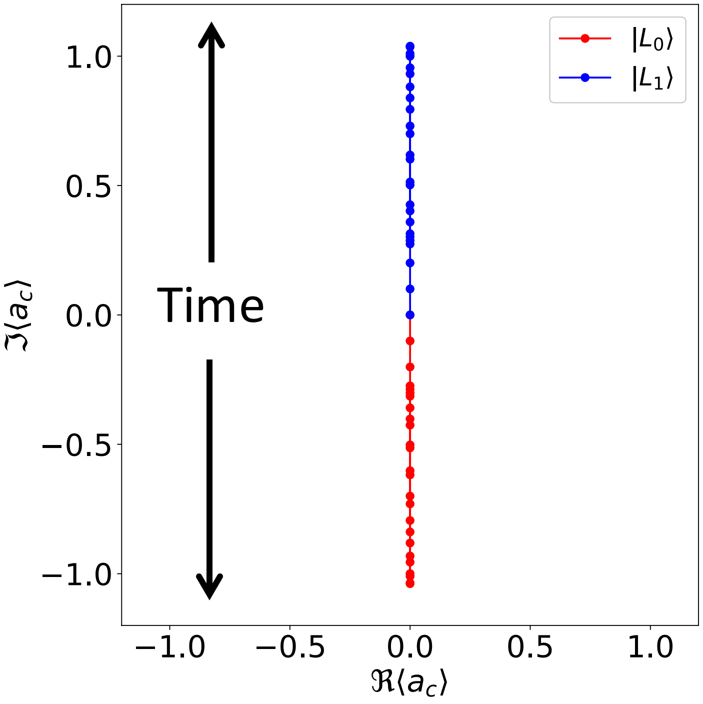
Results – Error, Logical States Distinguishable?

$$\left|\widetilde{L}_0\right\rangle = \left|1_l\right\rangle \frac{\left|2_r\right\rangle + \left|0_r\right\rangle}{\sqrt{2}} \left|0_{S_l}\right\rangle \left|0_{S_r}\right\rangle$$

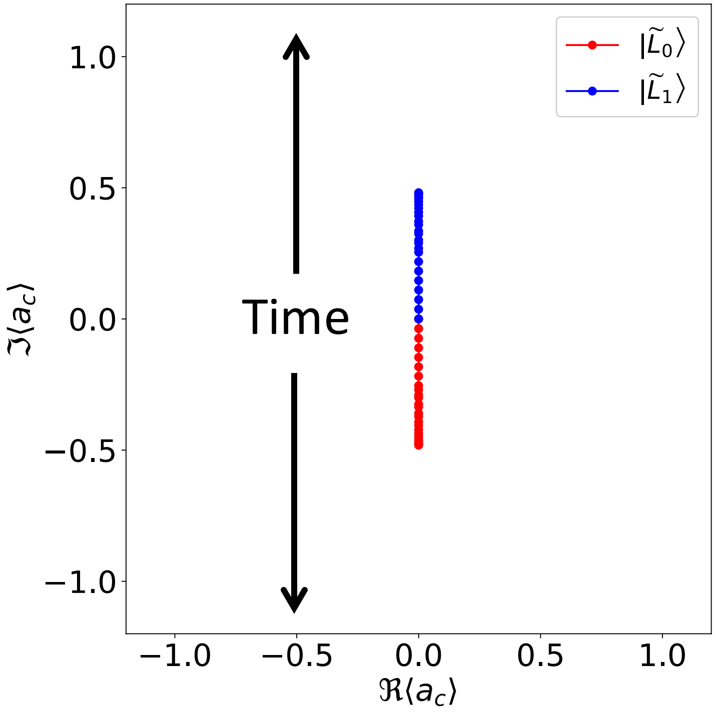
$$\left|\widetilde{L}_1\right\rangle = \left|1_l\right\rangle \frac{\left|2_r\right\rangle - \left|0_r\right\rangle}{\sqrt{2}} \left|0_{S_l}\right\rangle \left|0_{S_r}\right\rangle$$

Results – Error, Logical States Distinguishable?

Logical States



Error States



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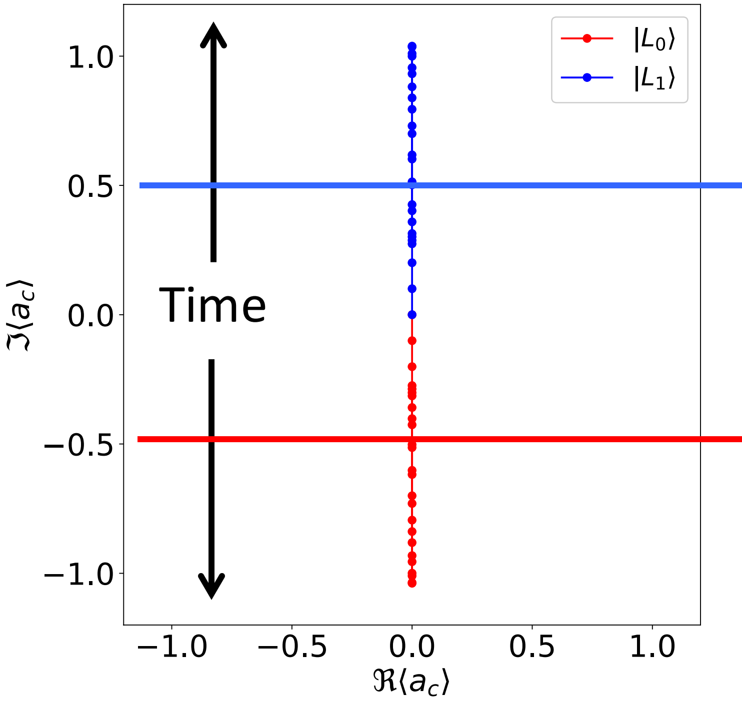
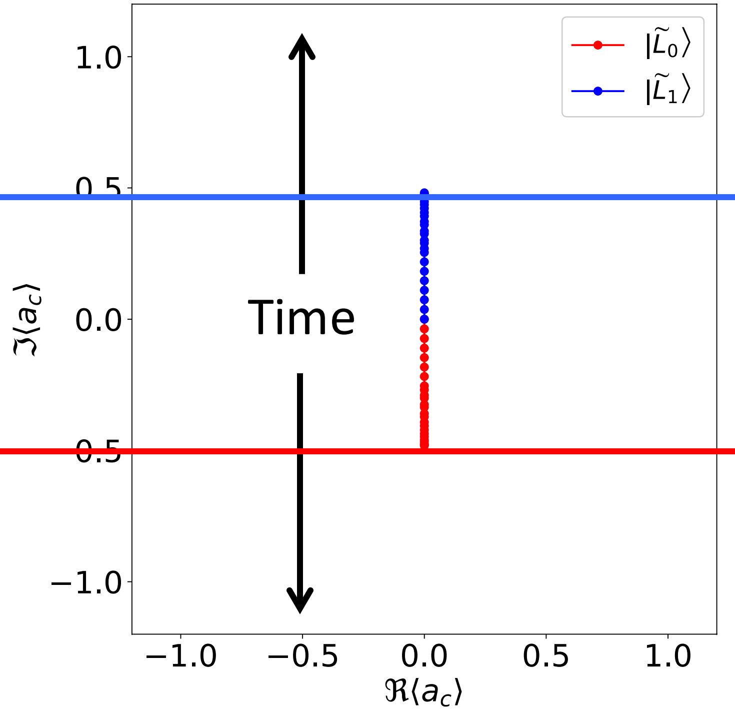
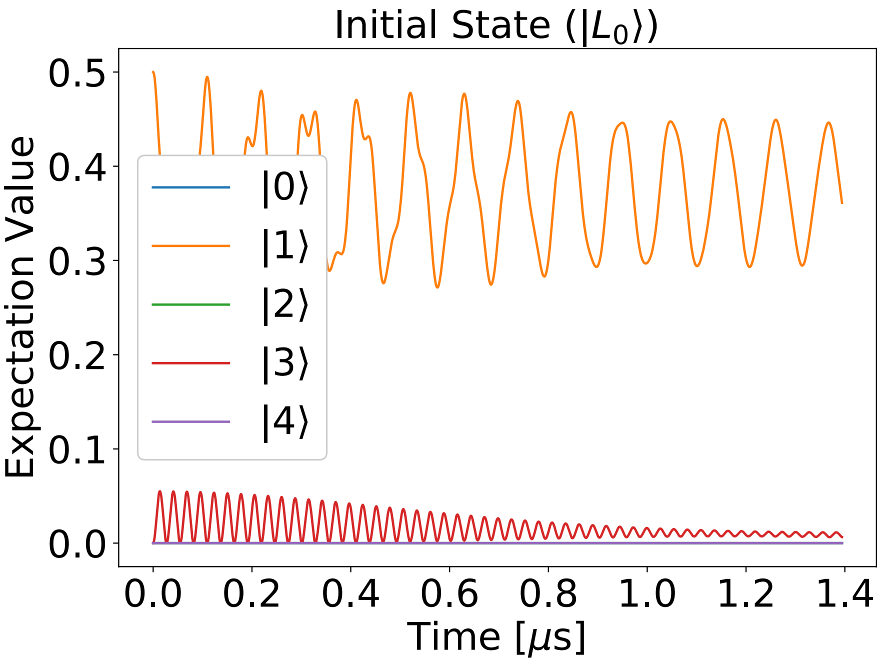
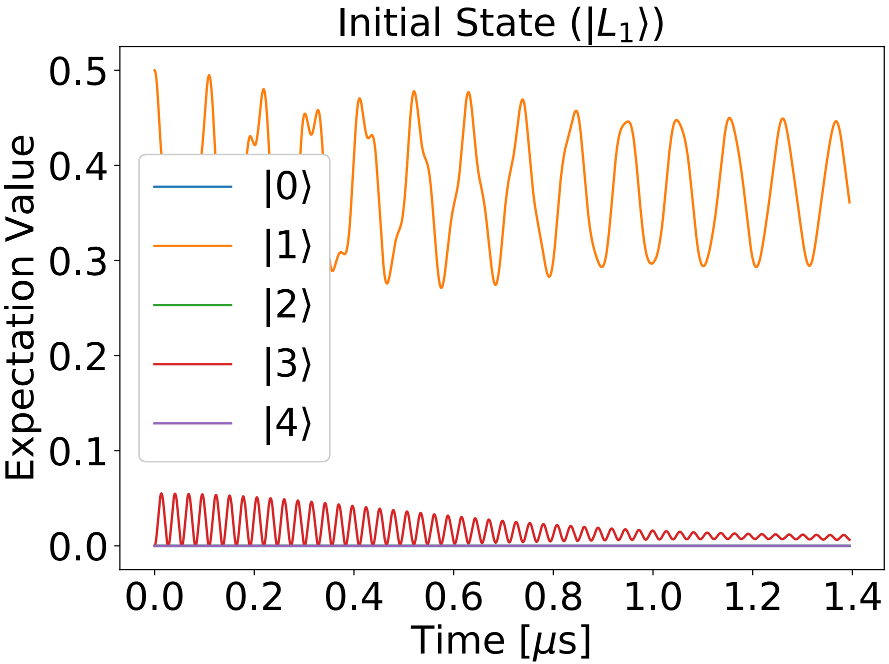


Error States



Results – Logical States, Negligible Mixing?





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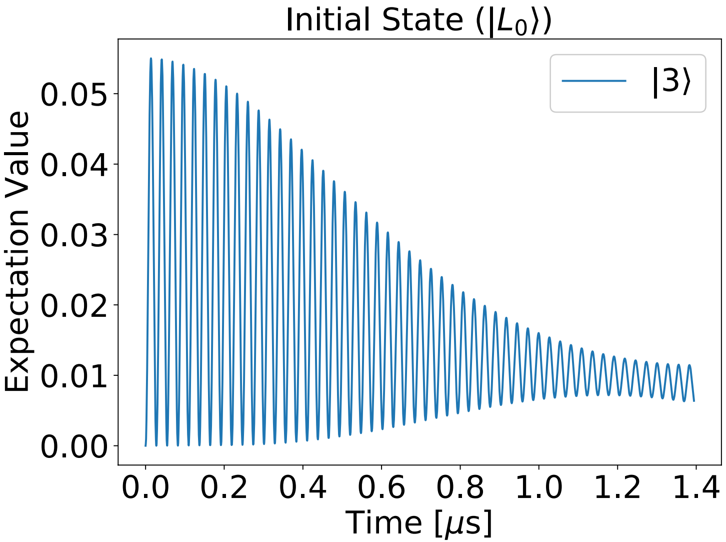
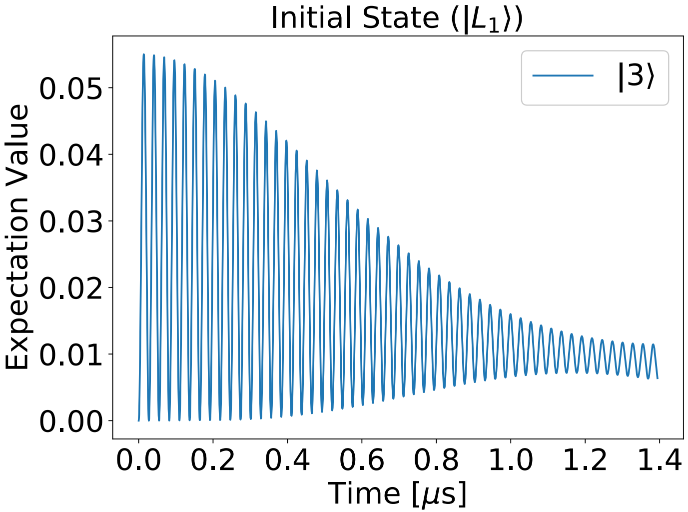
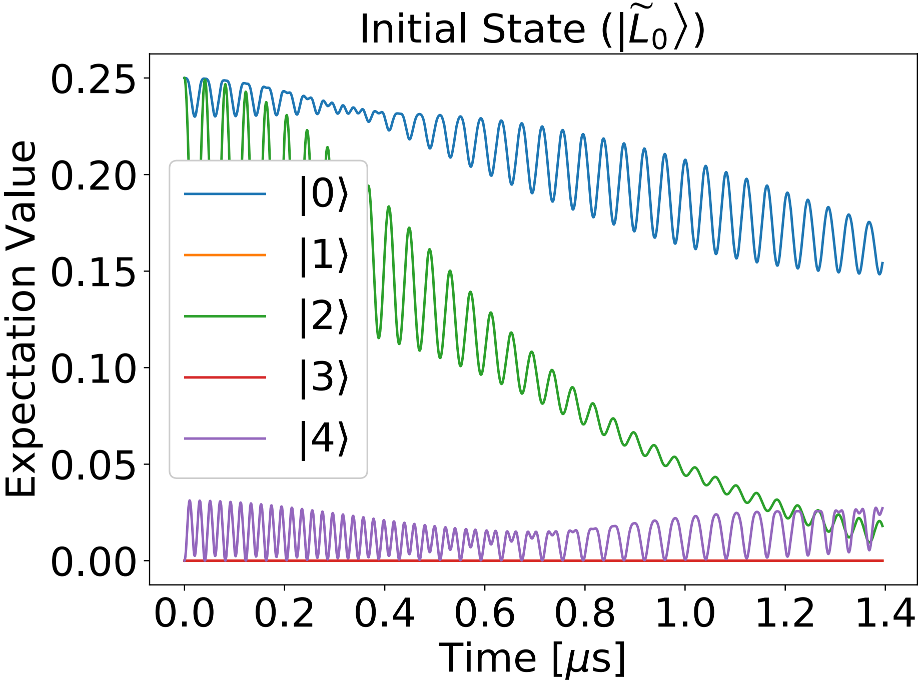
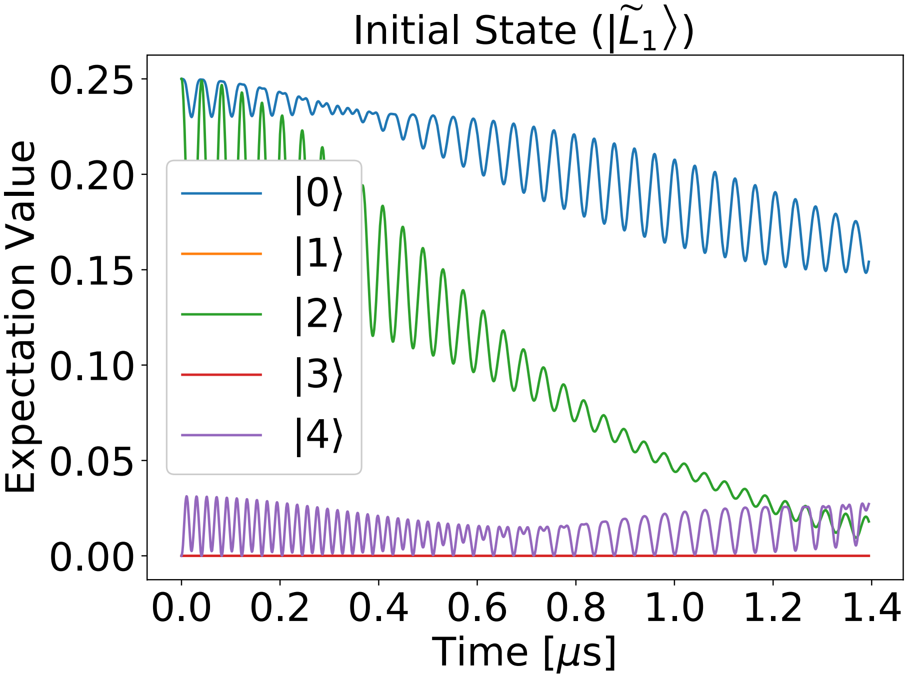




Results – Error States, Leakage?

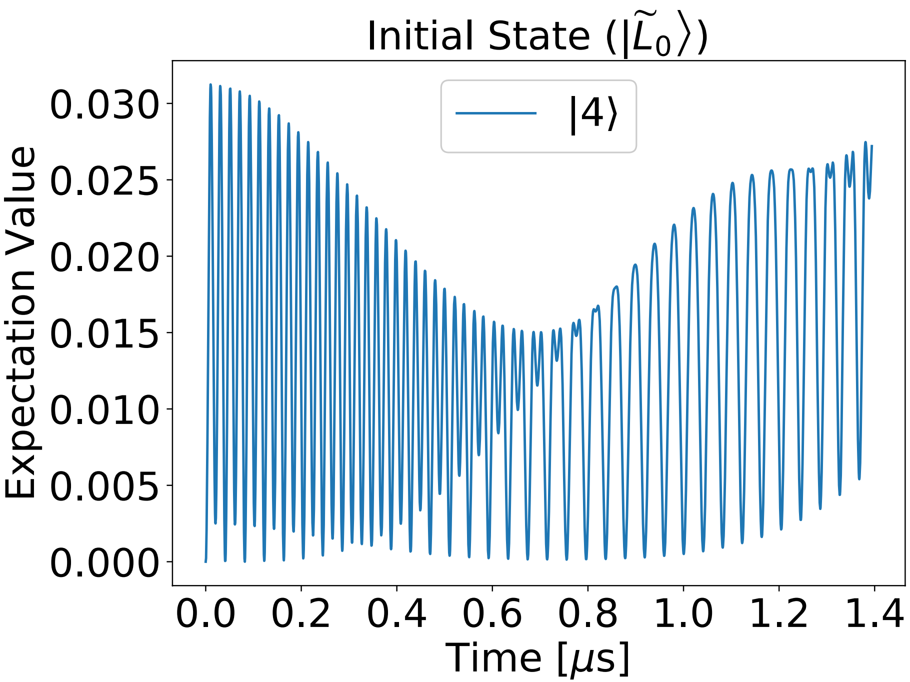


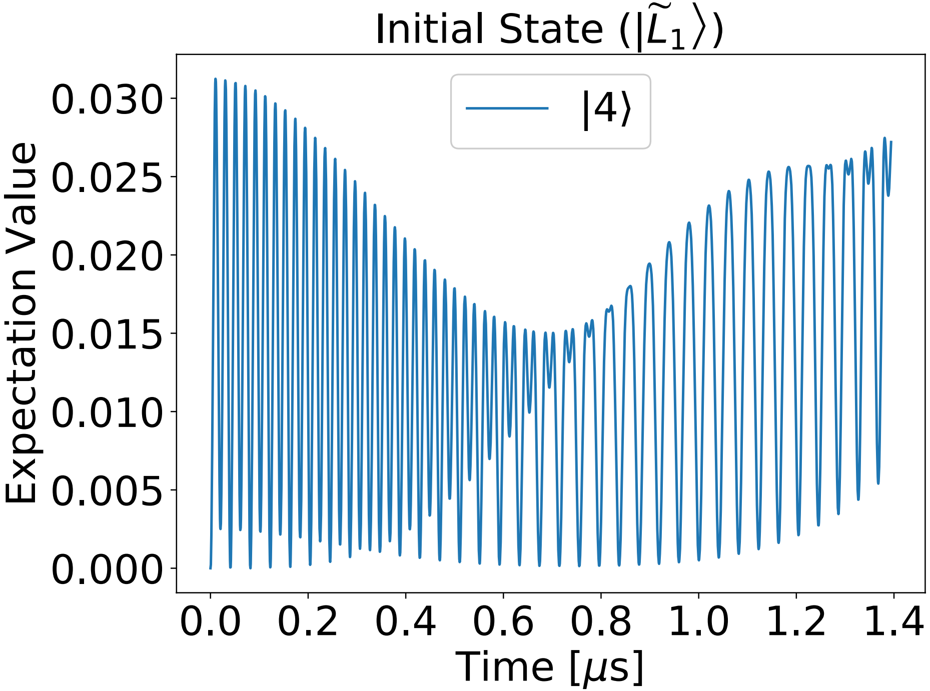
Initial State ($|\widetilde{L}_0\rangle$)



Initial State ($|\widetilde{L}_1\rangle$)

Results – Error States, Leakage?





Next Steps

- Study dephasing of logical state when there is a photon loss
- Signal optimization and precision cancellation of dispersive terms
- Add photon loss and full passive error correction terms
- Multi-cavity and device level design

Acknowledgements

This work was funded by a National Physical Sciences Consortium graduate fellowship and ARO grant W911NF-18-1-0125

I would like to thank David Rodriguez Perez, Mark Lusk, and Dustin Solomon for useful discussions and support of this work.

Thank you.