Simulations of Quantum Enhanced Interferometry Readout

Reilly Loughman

Mentors: Jeffrey Wack and Lee McCuller

California Institute of Technology

Outline

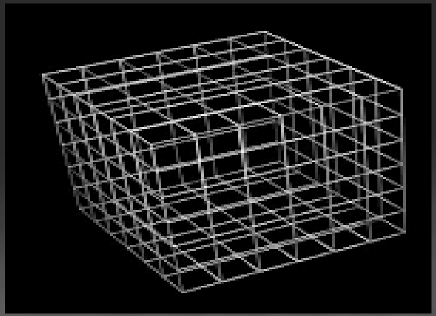
1. Introduction to GQuEST/RbQ
2. 2-Level Systems
3. Constructing 3-Level Systems
4. Testing and Optimizing 3-Level Systems

GQuEST

Goal: Describe gravity in quantum mechanics

Gravity = GR

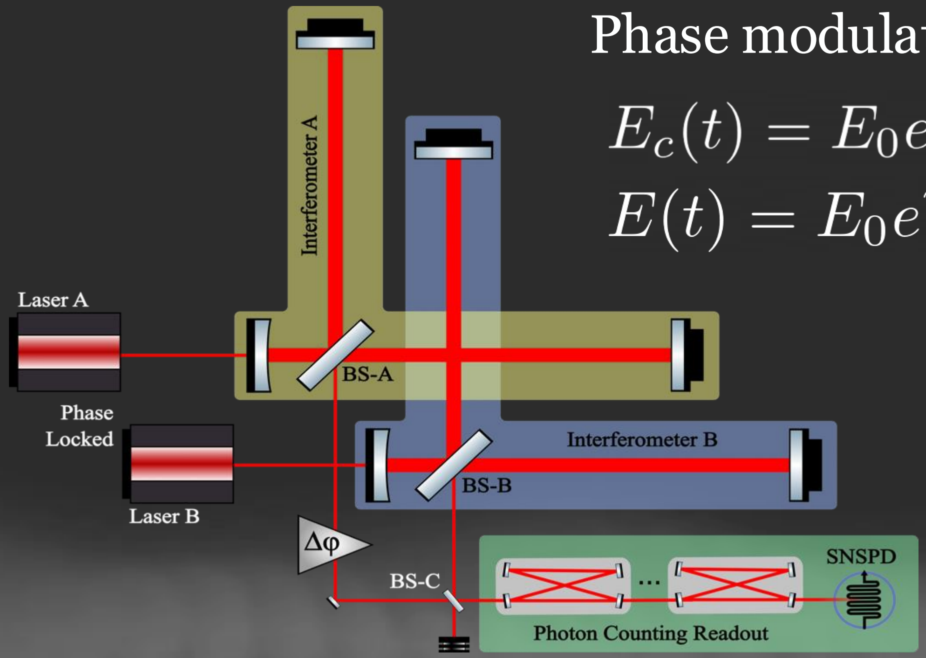
Spacetime geometry



Gravity = quantum

Exhibits stochastic fluctuations

Quantum fluctuations in spacetime



Phase modulation:

$$E_c(t) = E_0 e^{i\omega_c t} \rightarrow$$
$$E(t) = E_0 e^{i(\omega_c t + \delta\phi(t))}$$

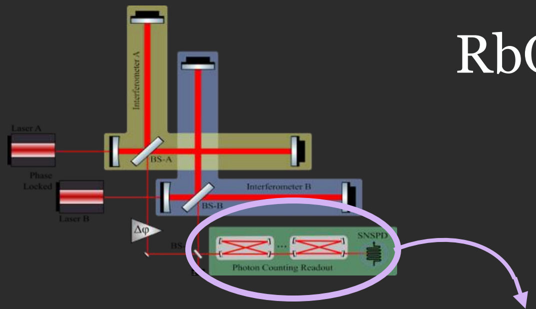
2 interferometers: cancel out noise

Arms = 7m: measurement frequency = 20MHz

Readout: filter cavities + single photon detector

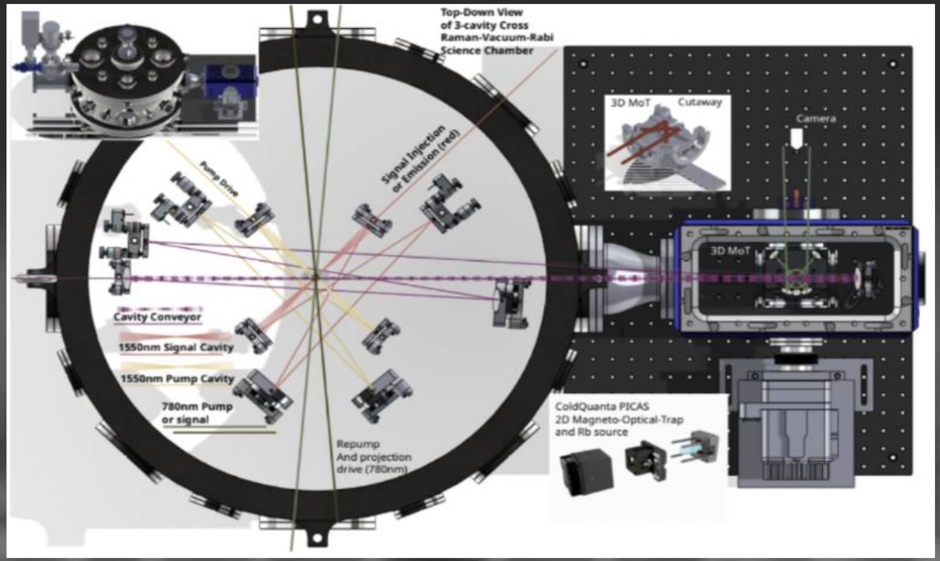
RbQ

Goal: Detect small sidebands from carrier frequency



RbQ: GQuEST + new readout scheme

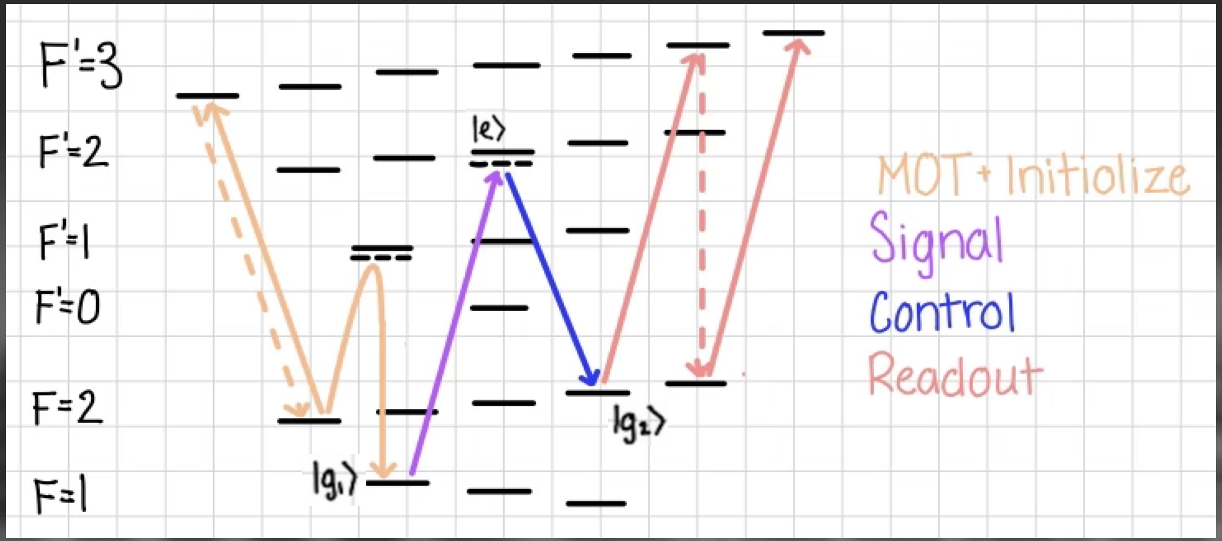
Readout system



Frequency filter:

$$E(t) = E_0 e^{i(\omega_c t + \delta\phi(t))} \quad \rightarrow \quad E_0 e^{i\delta\phi(t)}$$

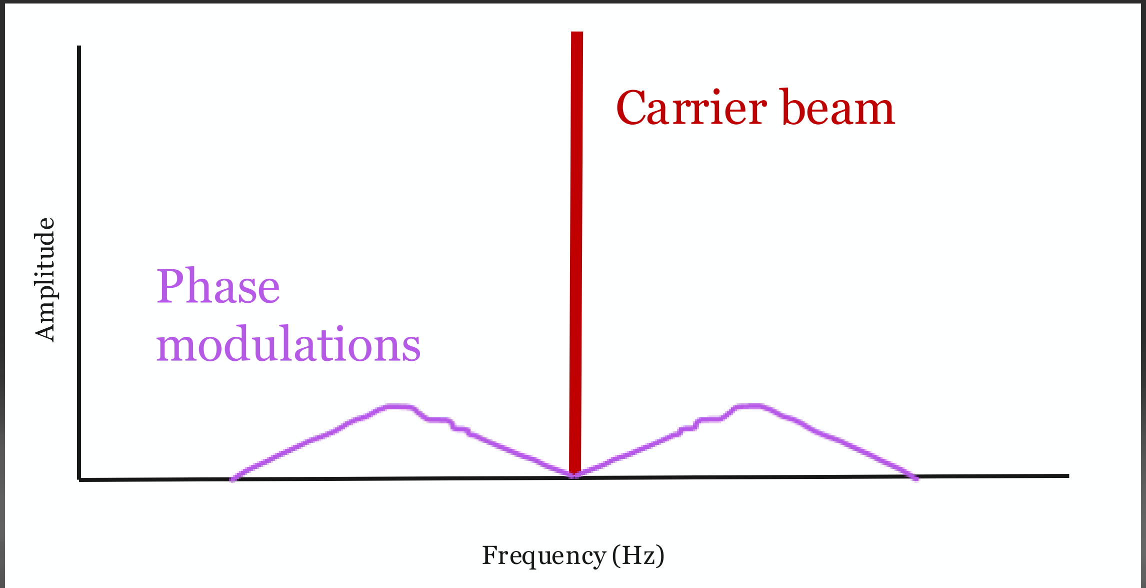
Rubidium 87 Transitions (counts photons):



Inside the Cavity

Project Goal: Determine parameters resulting in most accurate signal detection

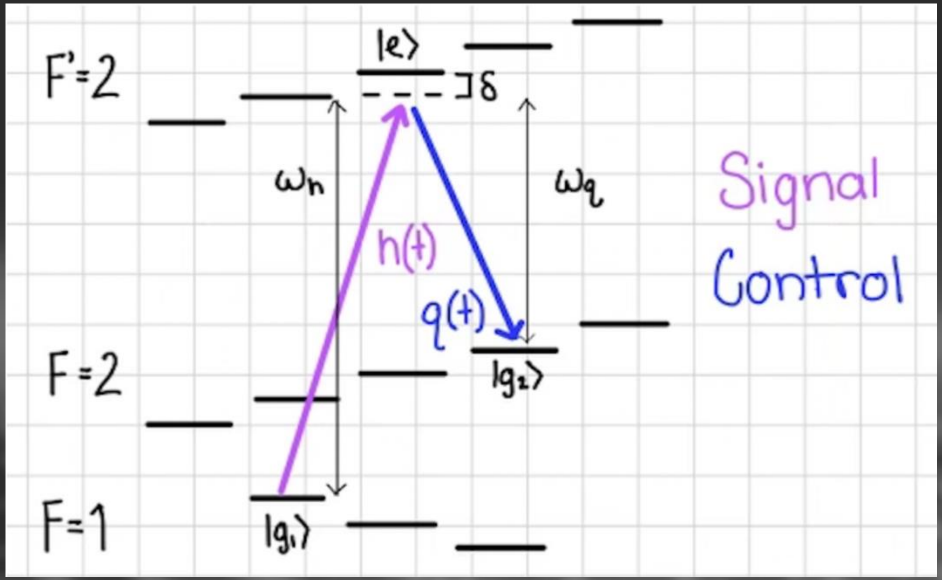
Signal from the interferometers:



Can tune control to this shape:
optimize absorption of signal and rejection of carrier

Parameters:

- Control frequency and shape
- Decay rates/loss



2-Level Systems

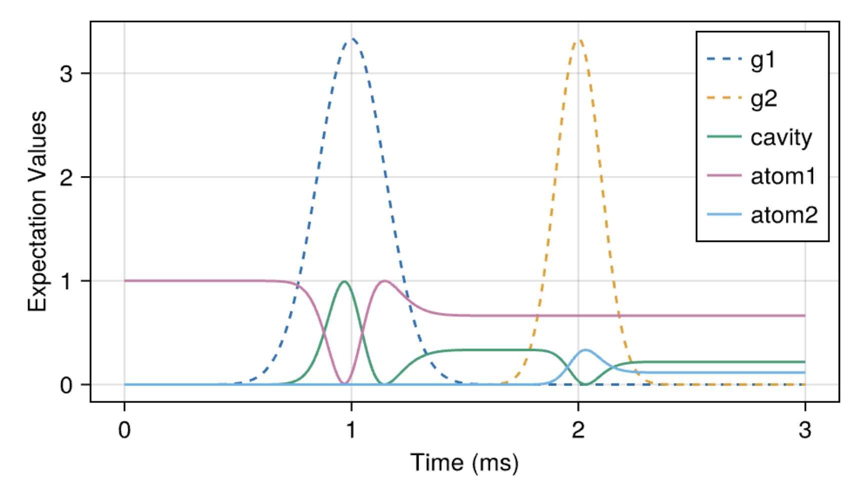
Two 2-Level Systems in Cavity

- Hamiltonian

$$\hat{H}_{total}(t) = \hat{H}_{\text{free atom}} + \hat{H}_{\text{interaction}}$$

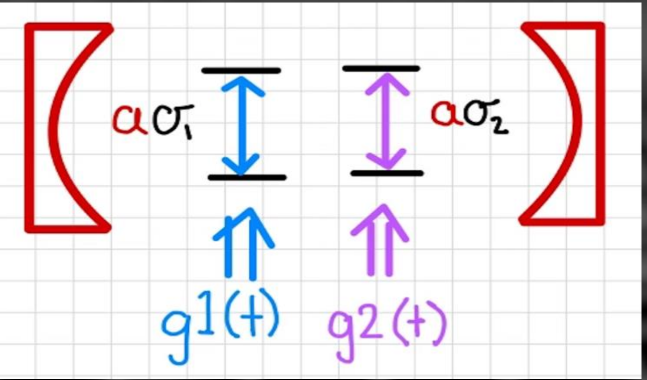
$$\hat{H}_{\text{int}} = g_1(t)\left(\hat{a}^\dagger\hat{\sigma}_1 + \hat{a}\hat{\sigma}_1^\dagger\right) + g_2(t)\left(\hat{a}^\dagger\hat{\sigma}_2 + \hat{a}\hat{\sigma}_2^\dagger\right)$$

$$\hat{H}_{\text{free atom}} = \omega_c\hat{a}^\dagger\hat{a} + \omega_1\hat{\sigma}_1^\dagger\hat{\sigma}_1 + \omega_2\hat{\sigma}_2^\dagger\hat{\sigma}_2$$



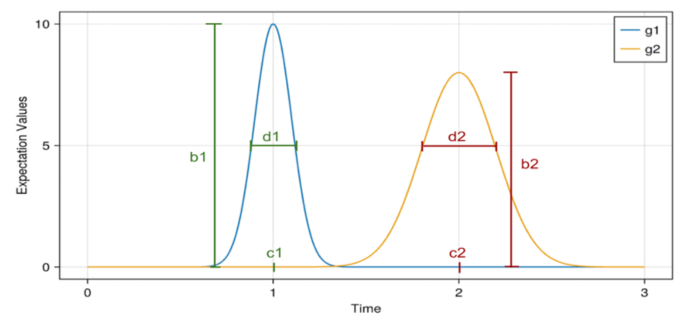
- Solve system: Lindblad master equation (QuantumToolbox in Julia)

$$\dot{\rho} = -\frac{i}{\hbar}[H,\rho] + \sum_i \gamma_i\left(L_i\rho L_i^\dagger - \frac{1}{2}L_i^\dagger L_i, \rho\right)$$

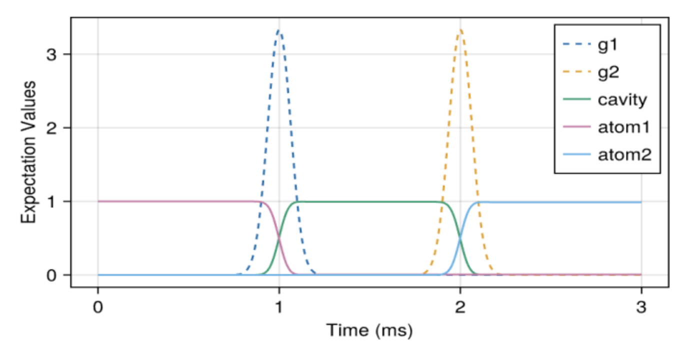


Optimize Gaussians

Setup:



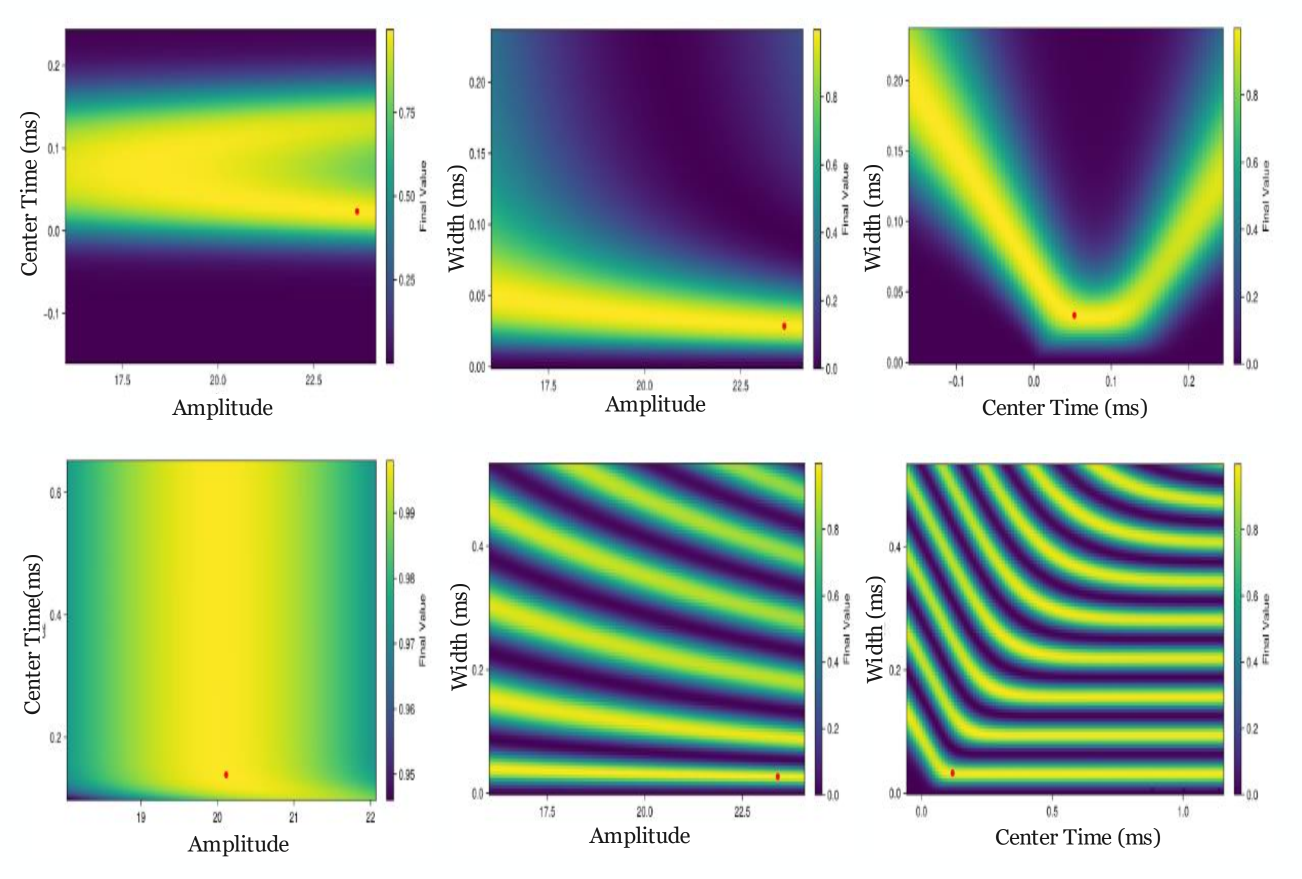
Result: atom2 = 0.9979



amp vs. center | amp vs. width | center vs. width

g1

g2



Constructing 3-Level Systems

Physical System

Hamiltonian:

$$H_{\text{tot}} = H_{\text{fa}} + H_{\text{cav}} + H_{\text{int}} + H_{\text{sig}} + H_{\text{cont}}$$

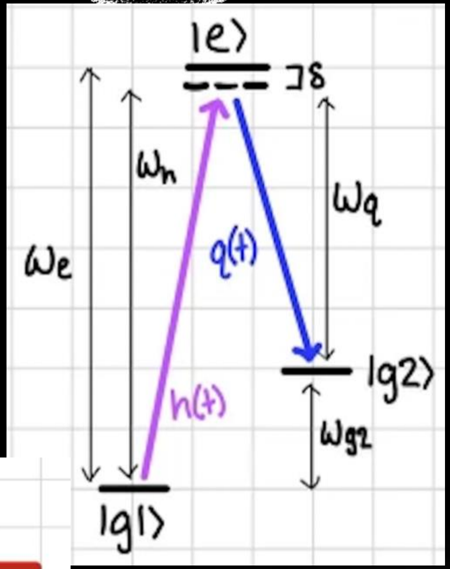
$$H_{\text{fa}} = \omega_{g2}|g2\rangle\langle g2| + \omega_e|e\rangle\langle e|$$

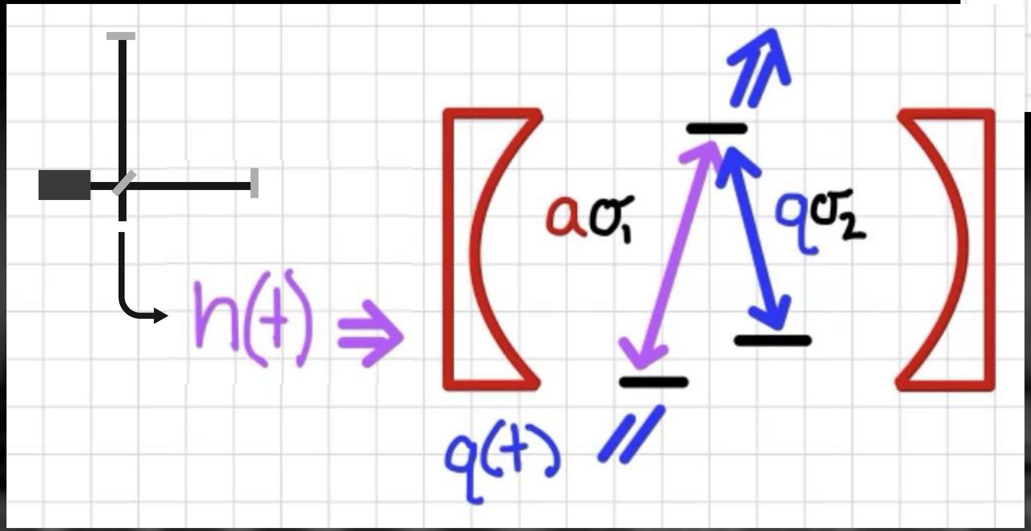
$$H_{\text{cav}} = \omega_c a^\dagger a$$

$$H_{\text{int}} = \Omega_1(a\sigma_1^\dagger + a^\dagger\sigma_1) + \Omega_2(a\sigma_2^\dagger + a^\dagger\sigma_2)$$

$$H_{\text{signal}} = (h(t)a^\dagger + h(t)^\dagger a)$$

$$H_{\text{control}} = (q(t)\sigma_2^\dagger + q(t)^\dagger\sigma_2)$$





Rotating Wave Approximation

1. Rotate: $\tilde{H} = \hat{U} H \hat{U}^\dagger + i\hbar(\frac{d}{dt}\hat{U})\hat{U}^\dagger$ -> ex. $\hat{U}_{\text{e-rot}} = \exp(i\omega_e t|e\rangle\langle e|)$

   $H_{\text{atom}} = H_{\text{cavity}} = 0$

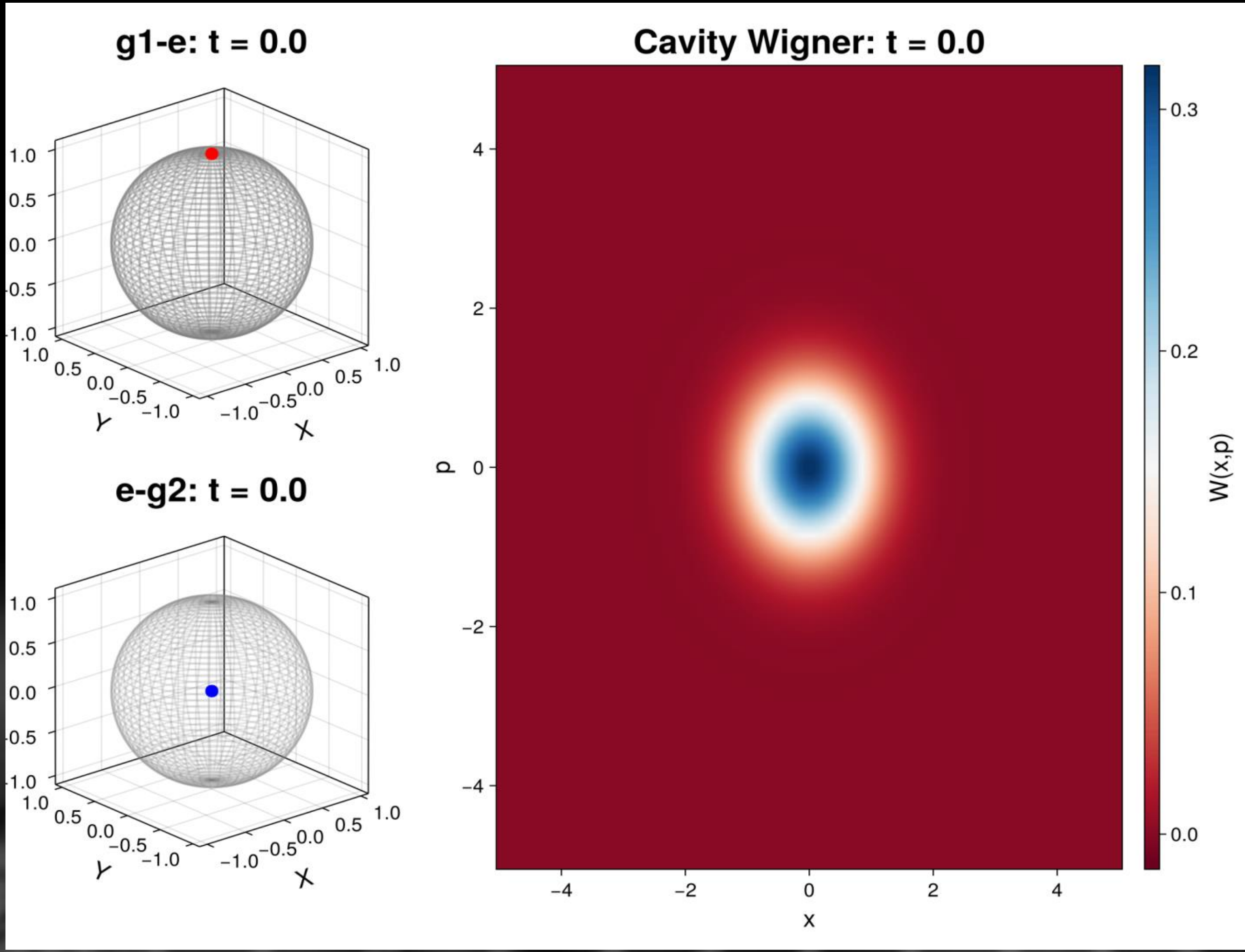
2. Cancel out fast terms

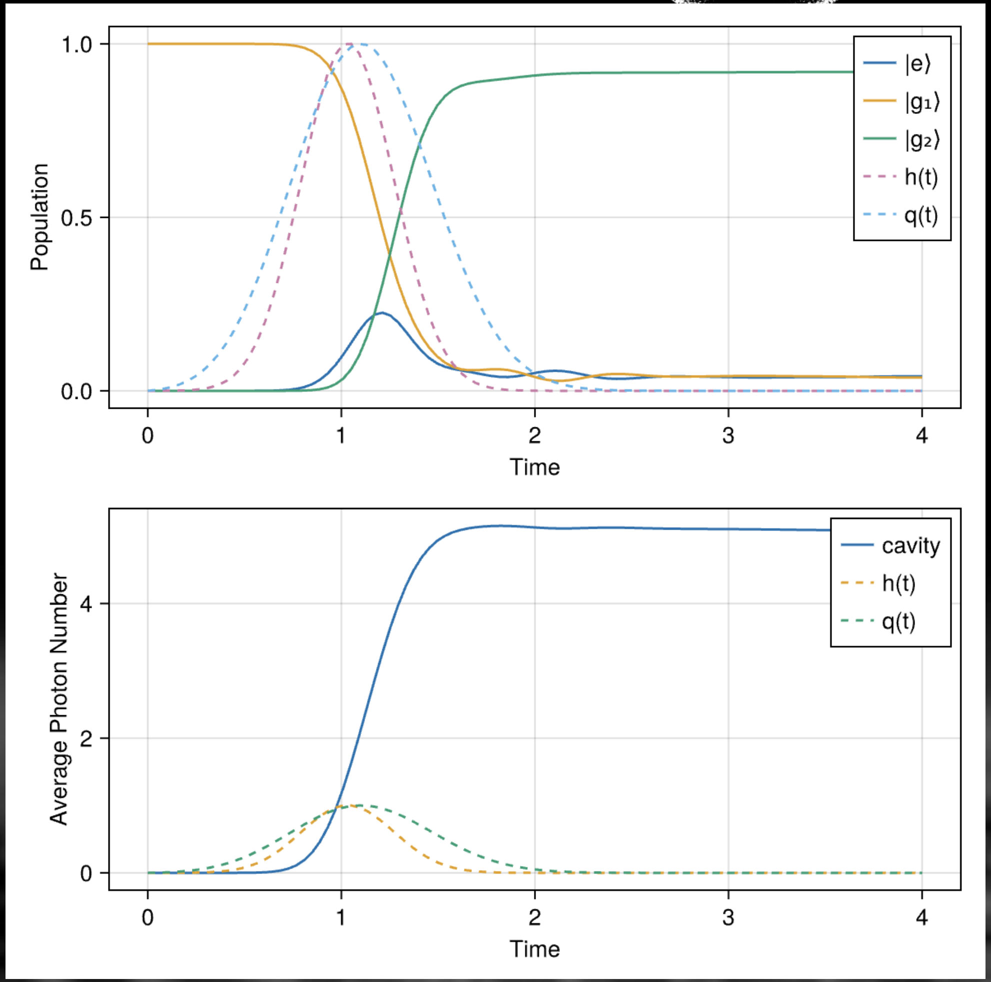
   $\exp(i\omega_h t) = \exp(i\omega_q t) = \exp(i\omega_{g2} t) = 1$

3. Resulting hamiltonian

$$\tilde{H} = \underbrace{\Omega_1(e^{i\delta t}a\sigma_1^\dagger + e^{-i\delta t}a^\dagger\sigma_1)}_{\text{σ1 and cav}} + \underbrace{(h(t)a^\dagger + h(t)^\dagger a)}_{\text{signal}} + \underbrace{(q(t)\sigma_2^\dagger + q(t)^\dagger\sigma_2)}_{\text{control}}$$

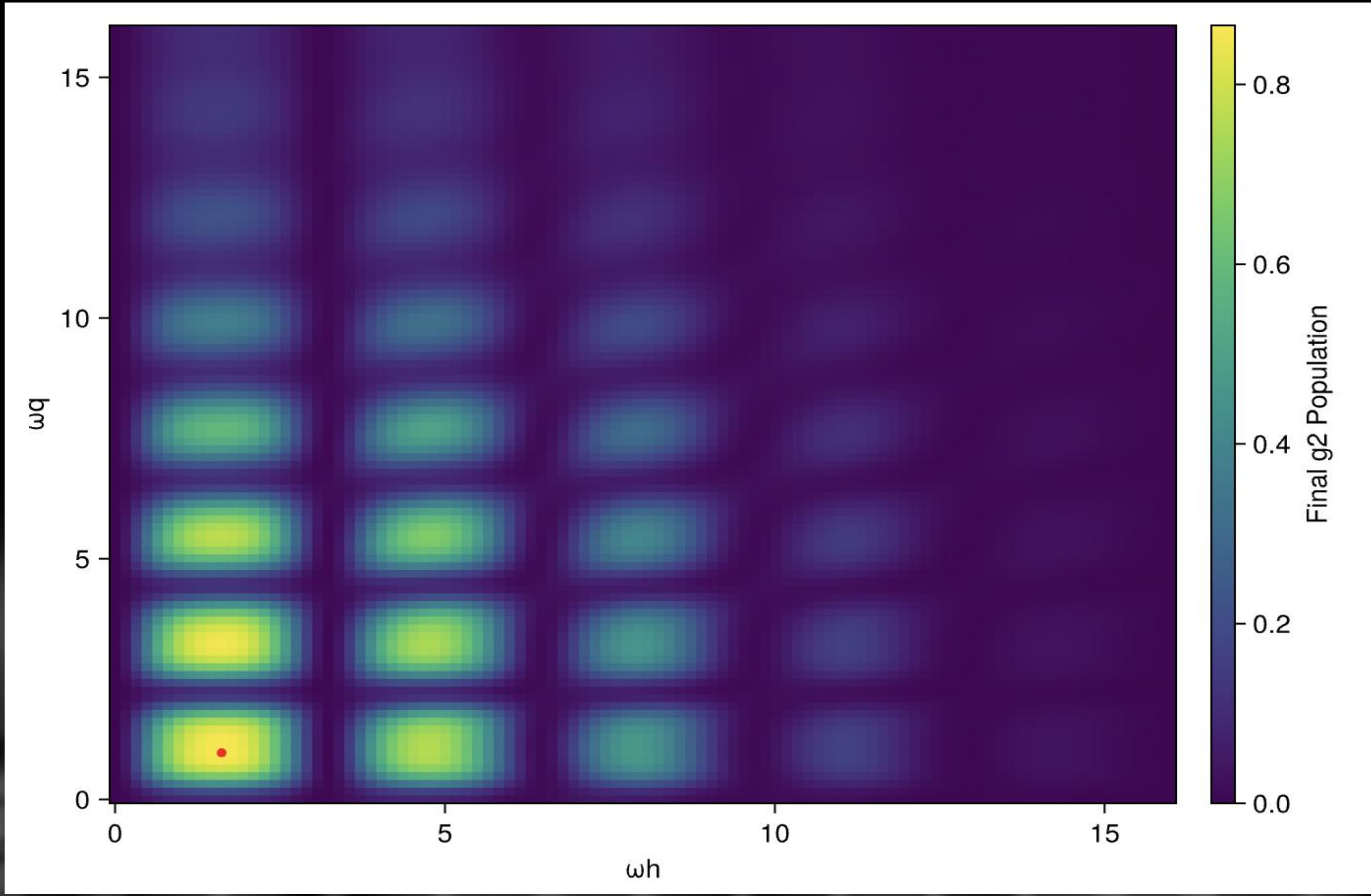
Time Dynamics



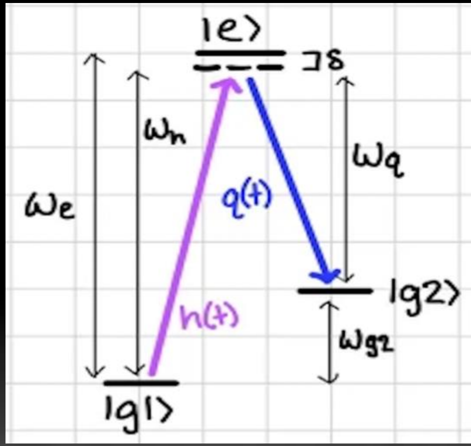


Testing and Optimizing 3-Level Systems

Frequency Comparisons

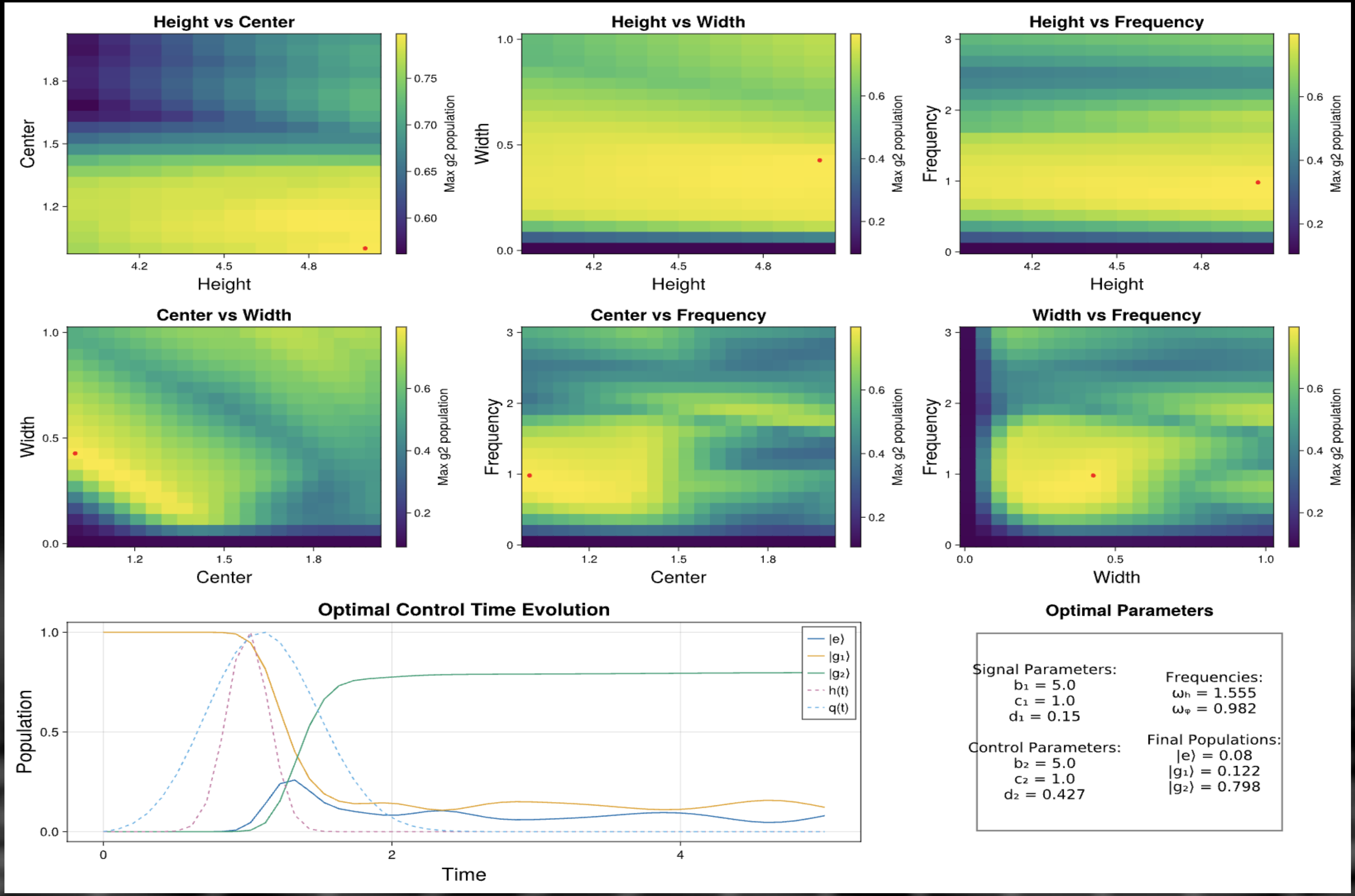


$$h(t) = g1(t) * \sin(i\omega_h t)$$
$$q(t) = g2(t) * \sin(i\omega_q t)$$



For each control ω ONLY SPECIFIC signal ω excite atom to g2!

Optimizing Control Parameters



Set signal parameters

↓

Iterate through control parameters

↓

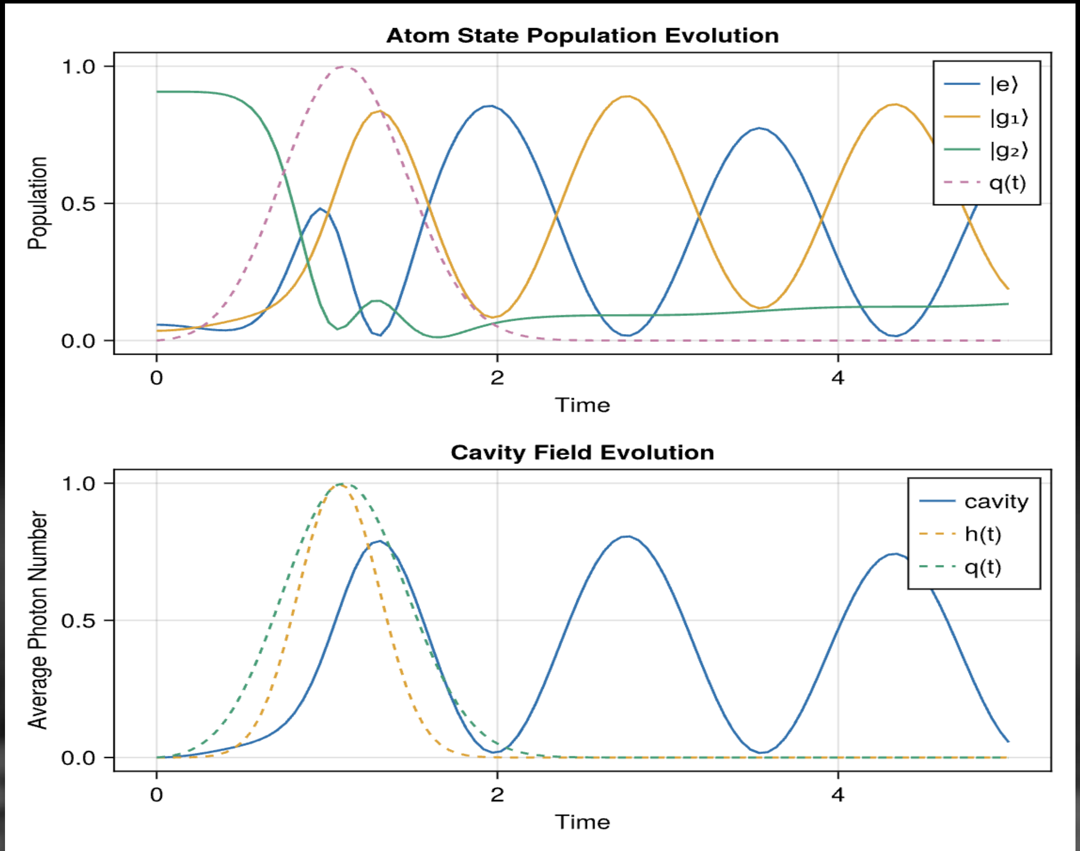
Find max g2 final value

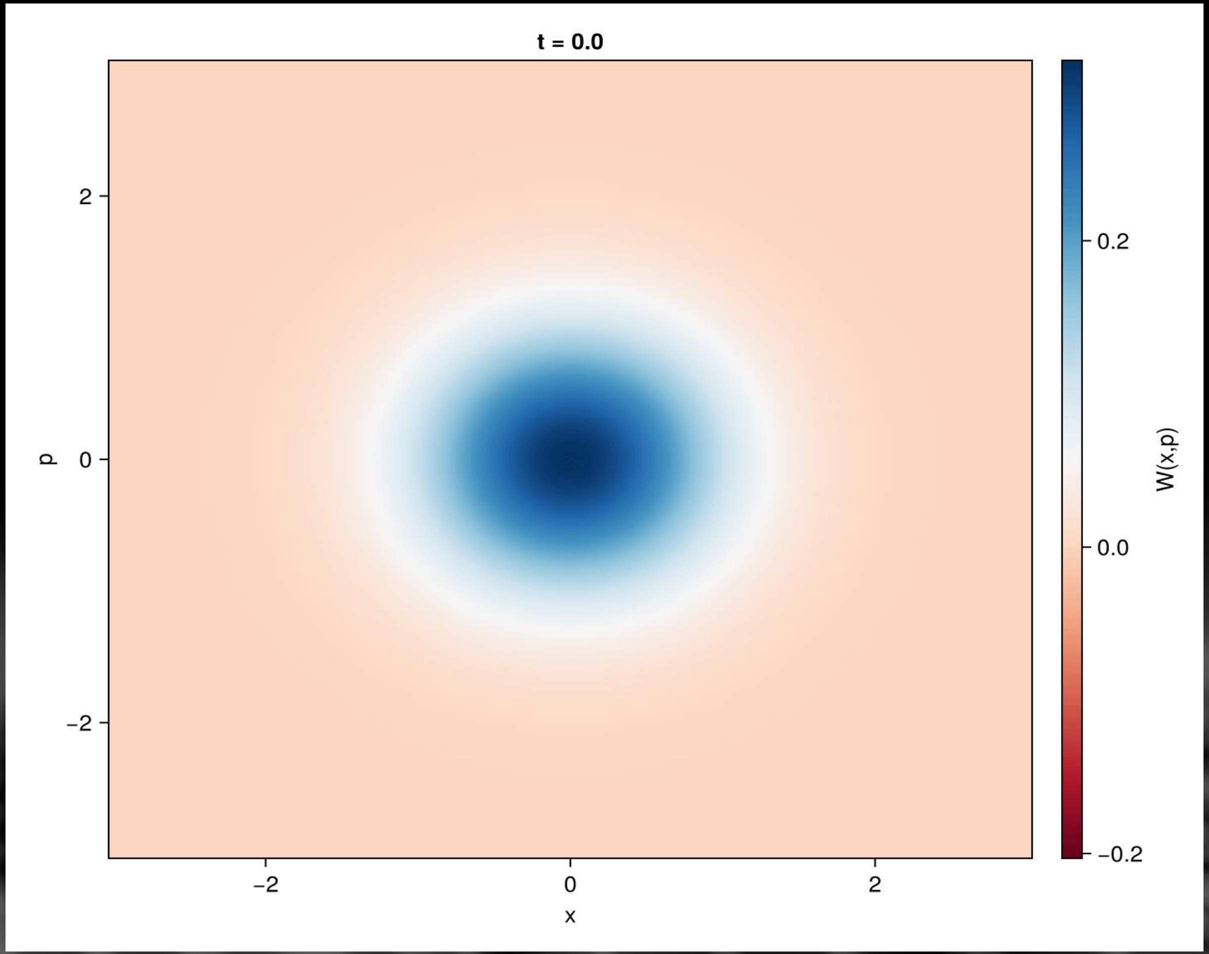
↓

Determine optimal control parameters

Signal Photon Release After Control

Initial state g2 → Send optimal control pulse → Receive signal photon





Application to RbQ

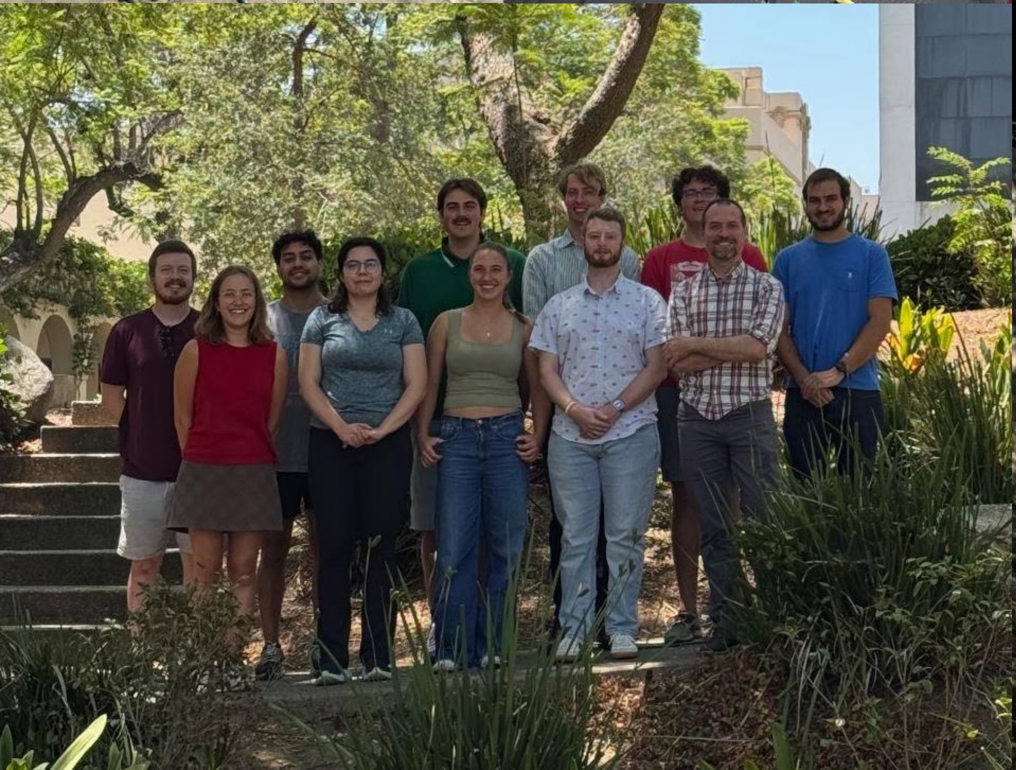
GQuEST

Accomplished

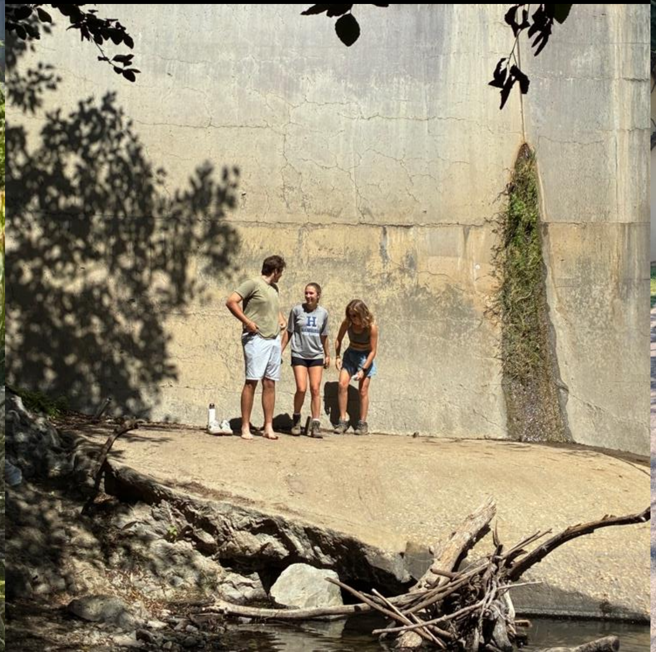
- Simulated toy model of RbQ
- Optimized gaussian signal absorption

Future

- Optimize expected signal
- Include more realistic cavity system
    - Include readout



Thank you!



Questions?

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