Improving the Quantum Zeno Gate with Post-selection

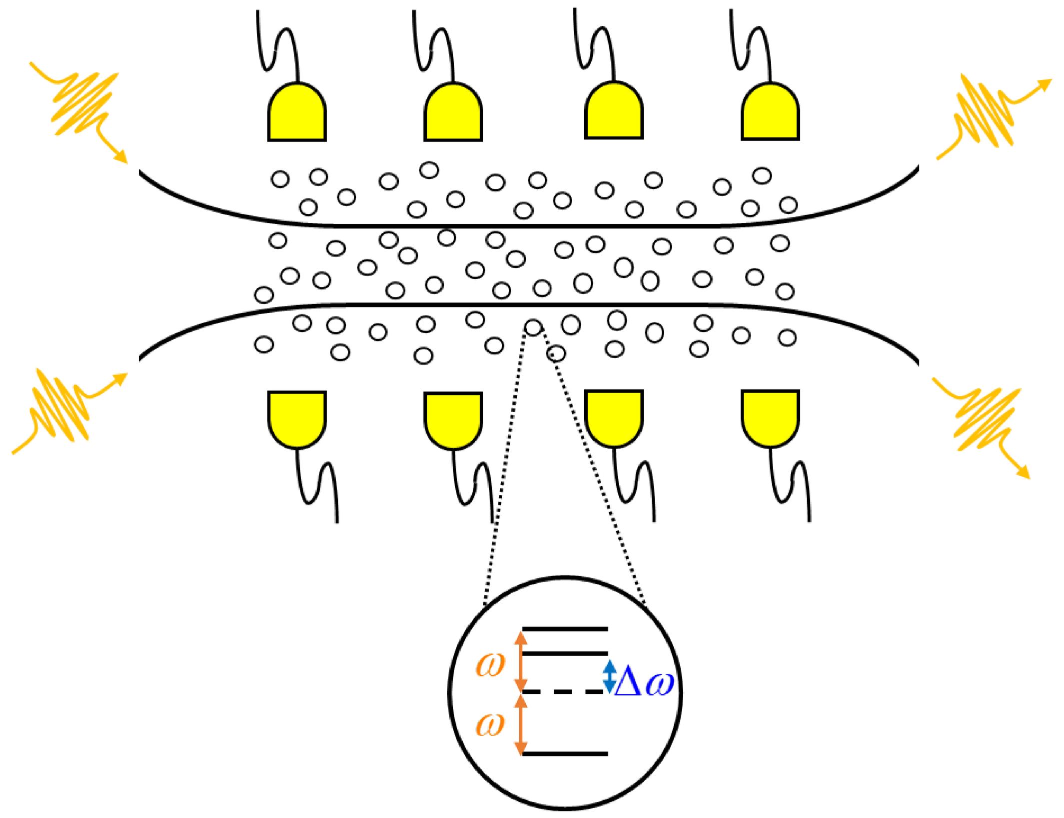
I.C. Nodurft and J.D. Franson
Physics Department, University of Maryland Baltimore County
1000 Hilltop Circle, Baltimore, MD 21250, USA
nodurft1@umbc.edu, jfranson@umbc.edu

Abstract

The quantum zeno effect exploits wavefunction collapse to keep quantum states from changing. We can use this effect to construct optical quantum logic gates. In this case, 3-level atoms play the role of the observer. We then post-select on their ground state to improve the gate's fidelity.

Introduction

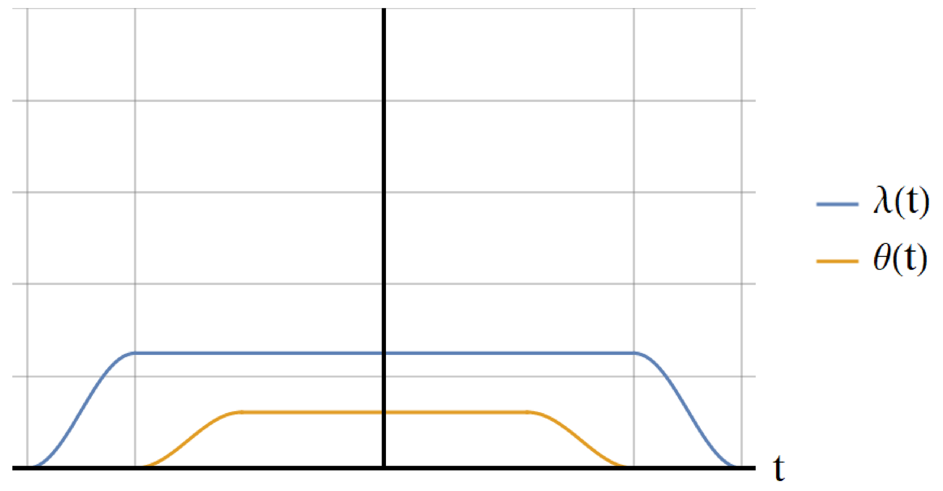
- A pair of coupled optical fibers can perform the beam splitter operation over an extended period.
- If many 3-level atoms are present in the coupled region, resonant with 2 but not 1 photon, we can prevent photon bunching [1].



- The gate depicted above is known as a $SWAP'$ gate and introduces a nonlinear phase shift for a 2-photon input (1 photon into each path).
- When combined with Post-selection, errors in operation can be suppressed.

Theory

- For our simulation, we slowly turn on and off both the atomic and fiber interactions. The process is:



- The Hamiltonian is made up by:

$$\hat{H}_a(t)+\hat{H}_b(t)=\hbar\omega\left(\hat{a}^\dagger\hat{a}+\hat{b}^\dagger\hat{b}+1\right),$$

$$\hat{H}_A(t)+\hat{H}_B(t)=\hbar\omega_0\left(\hat{A}_z+\hat{B}_z\right),$$

$$\hat{H}_I(t)=\hbar\lambda(t)\left(\hat{A}_+\hat{a}+\hat{A}_-\hat{a}^\dagger+\hat{B}_+\hat{b}+\hat{B}_-\hat{b}^\dagger\right),$$

$$\hat{H}_\theta(t)=\hbar\theta(t)\left(\hat{a}^\dagger\hat{b}+\hat{a}\hat{b}^\dagger\right).$$

- The nonlinear phase shift appears due to the suppressed bunching effect.
  - Normally the photons bunch and antibunch, picking up a net phase shift of π.
  - The $SWAP'$ gate, therefore, performs the transformation

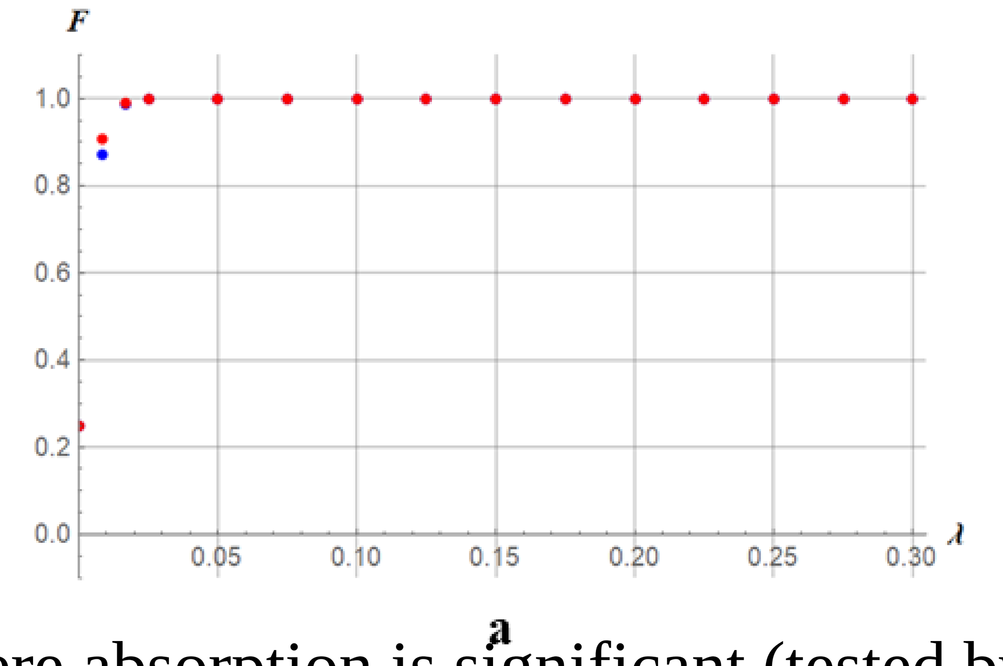
$$\hat{U}=\begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&-1\end{bmatrix}$$

Fidelity

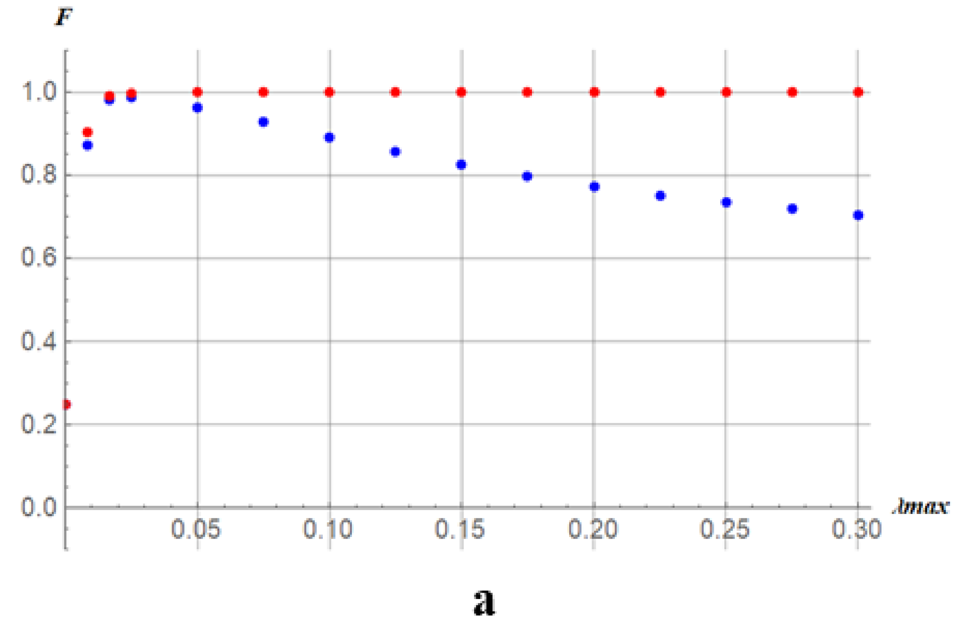
- The prime measurement for gate quality is fidelity F which is found by:

$$F=\overline{\langle\Psi_{in}|\hat{U}^\dagger\hat{\rho}_{out}\hat{U}|\Psi_{in}\rangle}$$

- The overline shows averaging over $|\Psi_{in}\rangle$.
- We tested the ideal case where there were no sources of error:



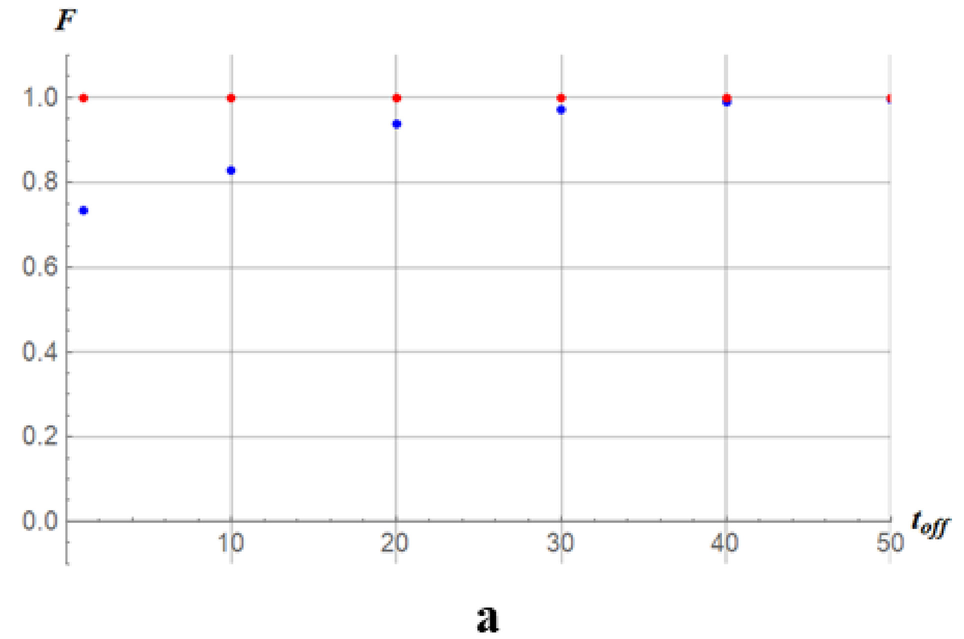
- Where absorption is significant (tested by turning off the atomic coupling quickly):



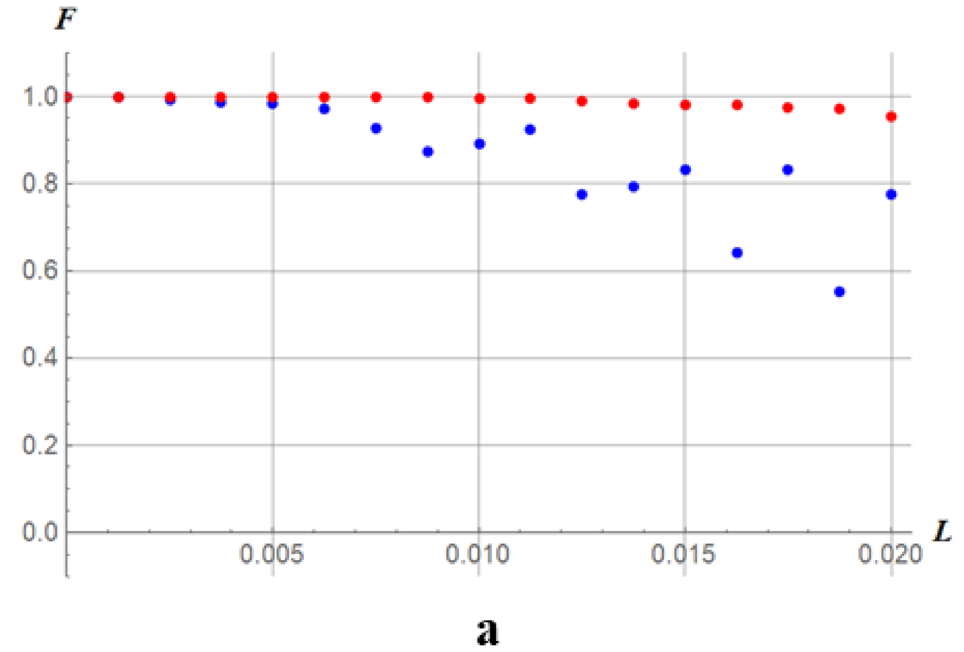
References

[1] J.D. Franson, B.C. Jacobs, and T.B. Pittman, Phys. Rev. A **70**, 062302 (2004)

- Varying the "turn off" time:



- And by introducing losses:



- This is shown as all the blue dots show the gates normal fidelity while the red show the post-selected fidelity.
- For the first three cases, the phase shift stays close to π.
- When losses are relatively large, the phase shift errors are significant.
- Overall, post-selection can yield much improvement in the gate operation.