

# Hybrid Quantum Annealing and Quantum Walk

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# Agenda

Introduction to Continuous-time Quantum Walk

Hybrid Quantum Annealing and Continuous-time Quantum Walk

Hybrid Reverse Annealing and Continuous-time Quantum Walk

Proposed Experimental Set-up

# Introduction

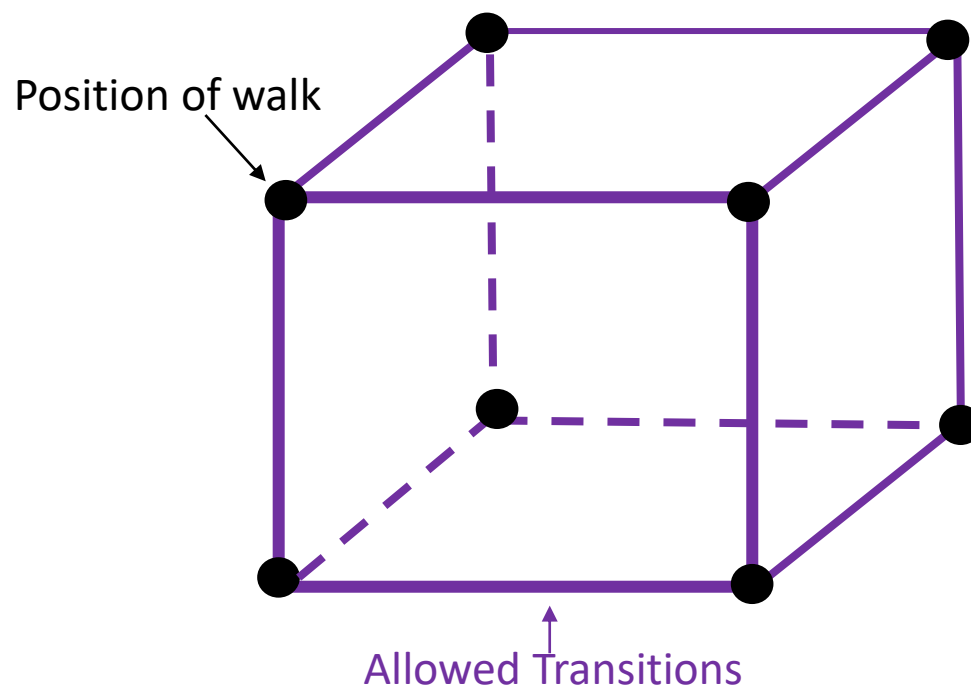
$$H(s) = A(s)H_{driver} + B(s)H_{problem}$$

$$H_{driver} = - \sum_i \sigma_i^x$$

$$s = \frac{t}{t_{anneal}}$$

$$H_{problem}(\sigma) = - \sum_i h_i \sigma_i^z - \sum_{i < j} J_{ij} \sigma_i^z \sigma_j^z$$

# Continuous-time Quantum Walk



# Pre-annealed Quantum Walk- *Adam Callison et al*

Start with equal superposition of all solutions :

$$|\omega\rangle = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} |j\rangle$$

$$\hat{H}(\gamma) = \underbrace{\hat{H}_G}_{\text{Hopping rate}} + \underbrace{\hat{H}_{problem}}_{\text{Ising spin model}}$$

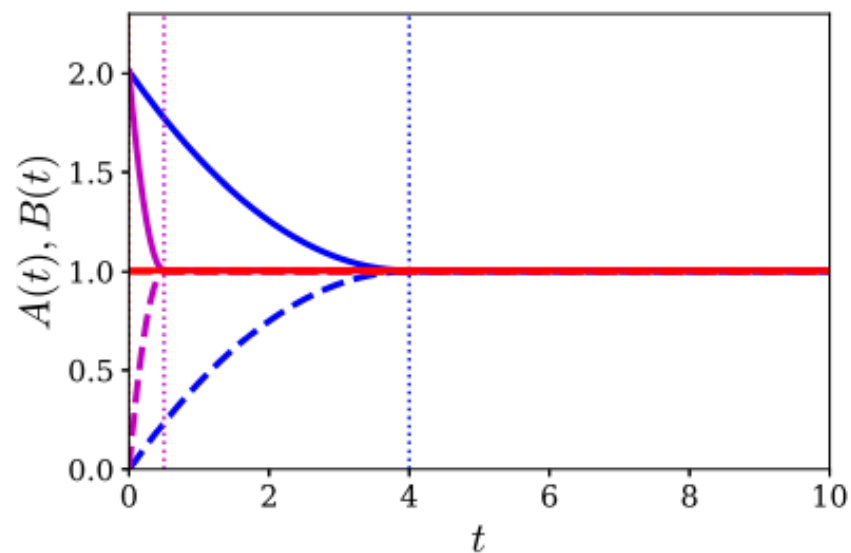
Quantum walk Hamiltonian

*New J. Phys.* **21** 123022

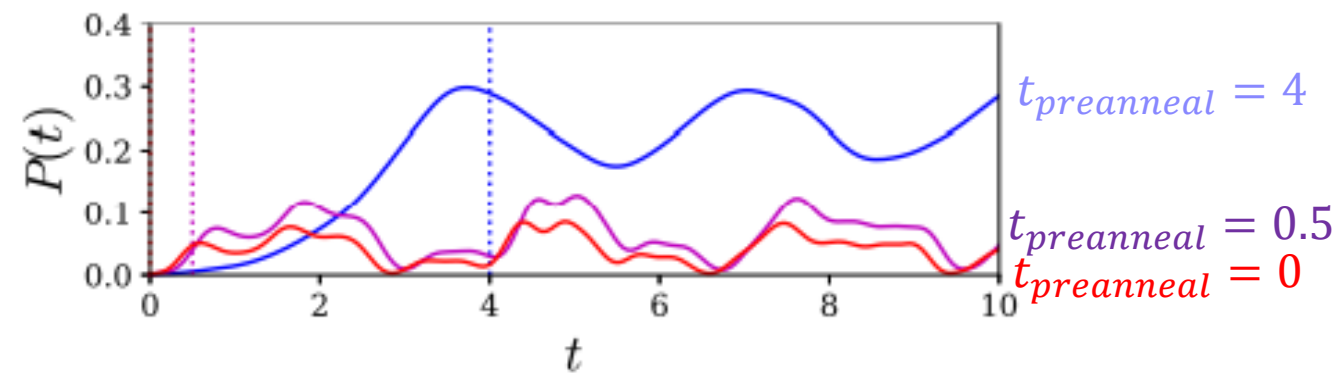
\* See talk by Adam Callison at 17:00 on  
6/22/2021 JST

# Pre-annealed Quantum Walk- *Adam Callison et al*

Annealing  
Schedule:



Energy expectation  
during an anneal:



PRX QUANTUM 2, 010338 (2021)

\* See talk by Adam Callison at 17:00 on  
6/22/2021 JST

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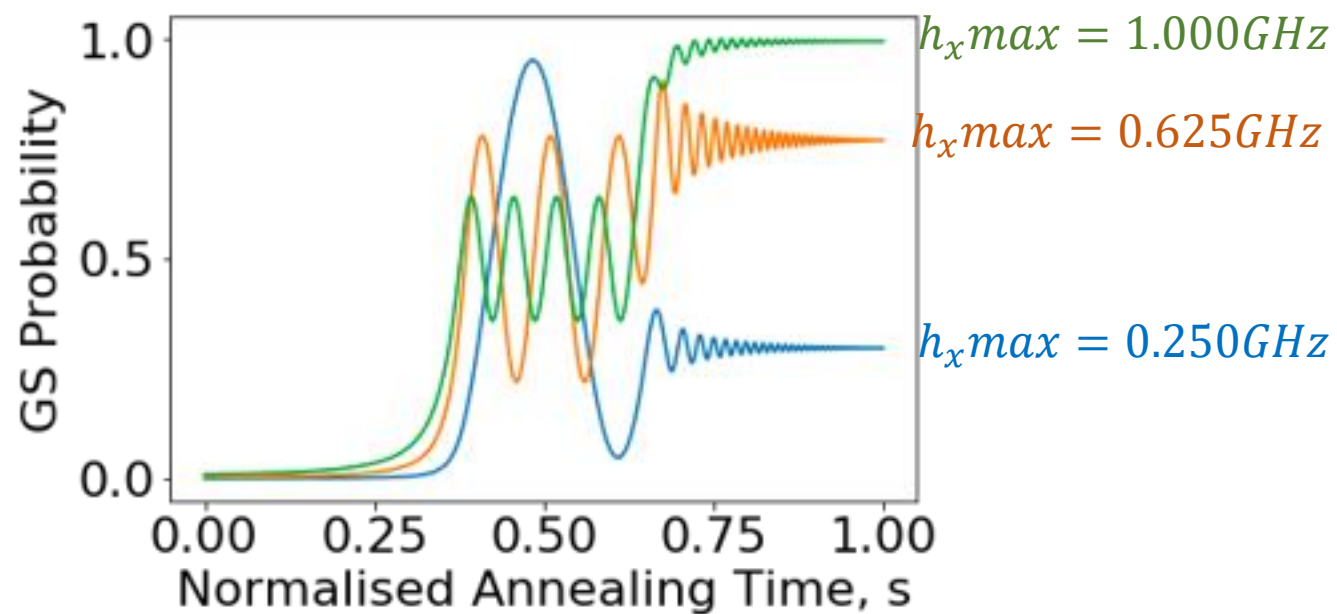
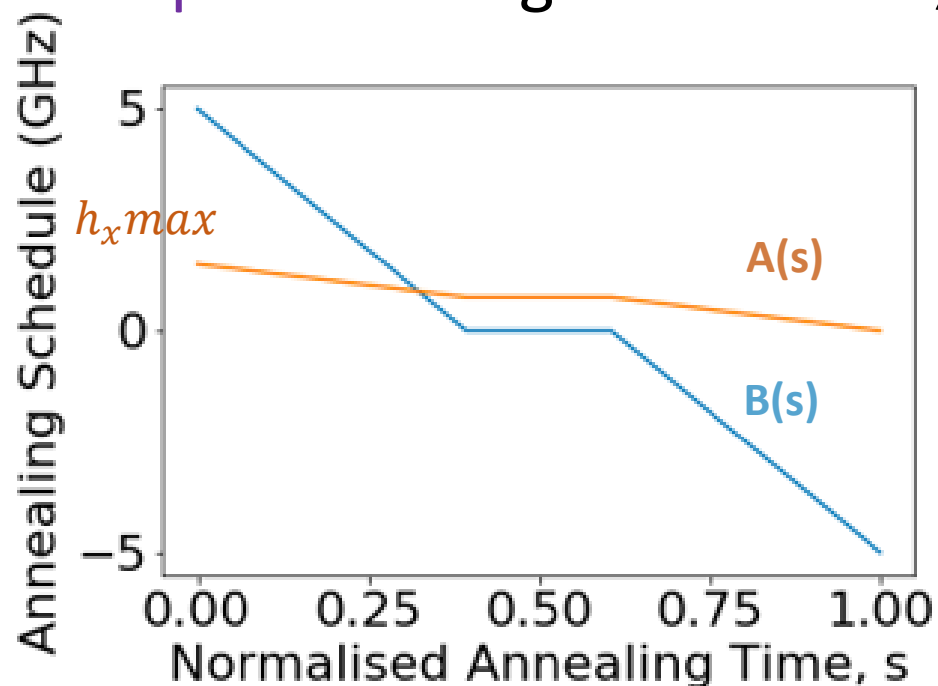
Proposed Experimental Set-up

**Motivation:** examine the coherent quantum processes during the quantum random walk

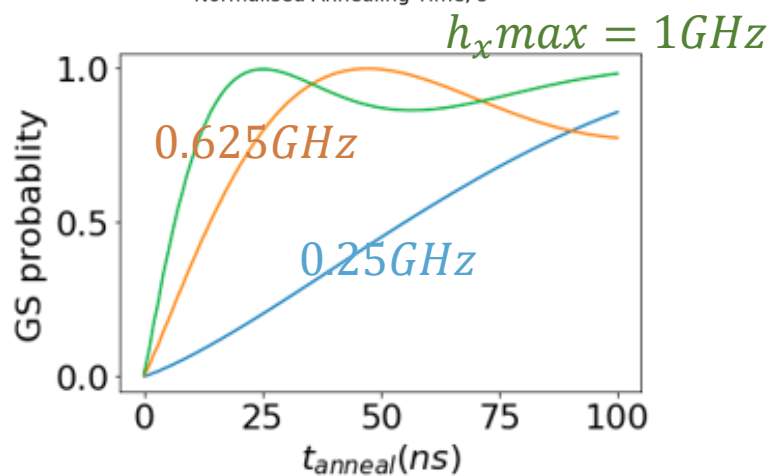
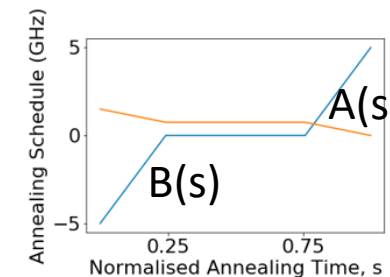
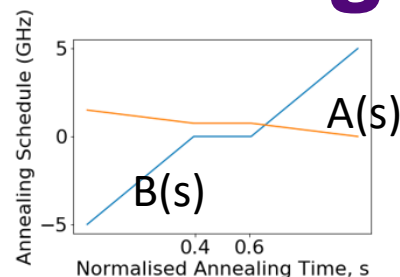
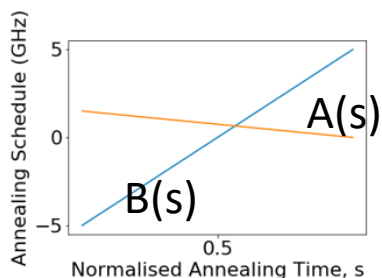


# Hybrid Forward Annealing and Continuous-time Quantum Walk – Single Qubit

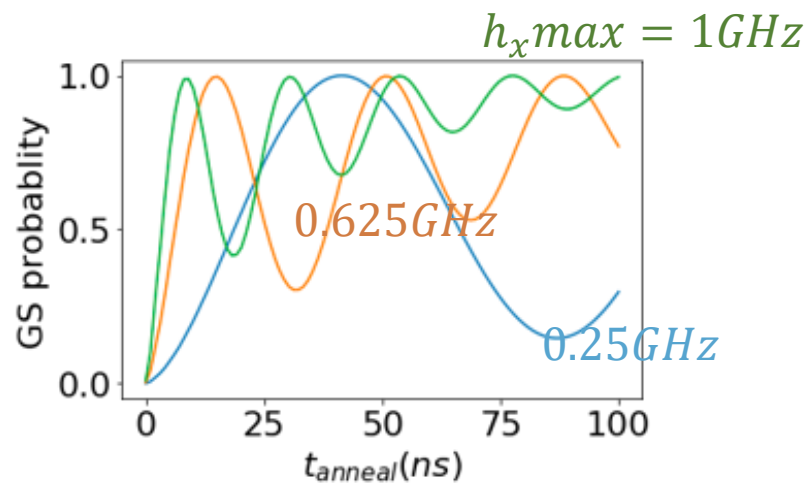
- Start at a **finite** transverse field, and **decrease** monotonically to **zero**
- Start at a **positive** longitudinal field, and **decrease** monotonically to **negative**



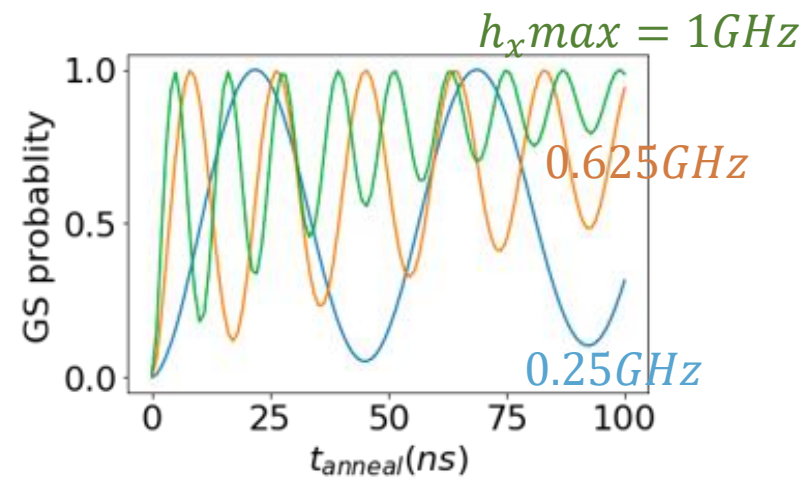
# Hybrid Forward Annealing and Continuous-time Quantum Walk – Single Qubit



No Pause



20% Pause



50% Pause

# Agenda

Introduction to Continuous-time Quantum

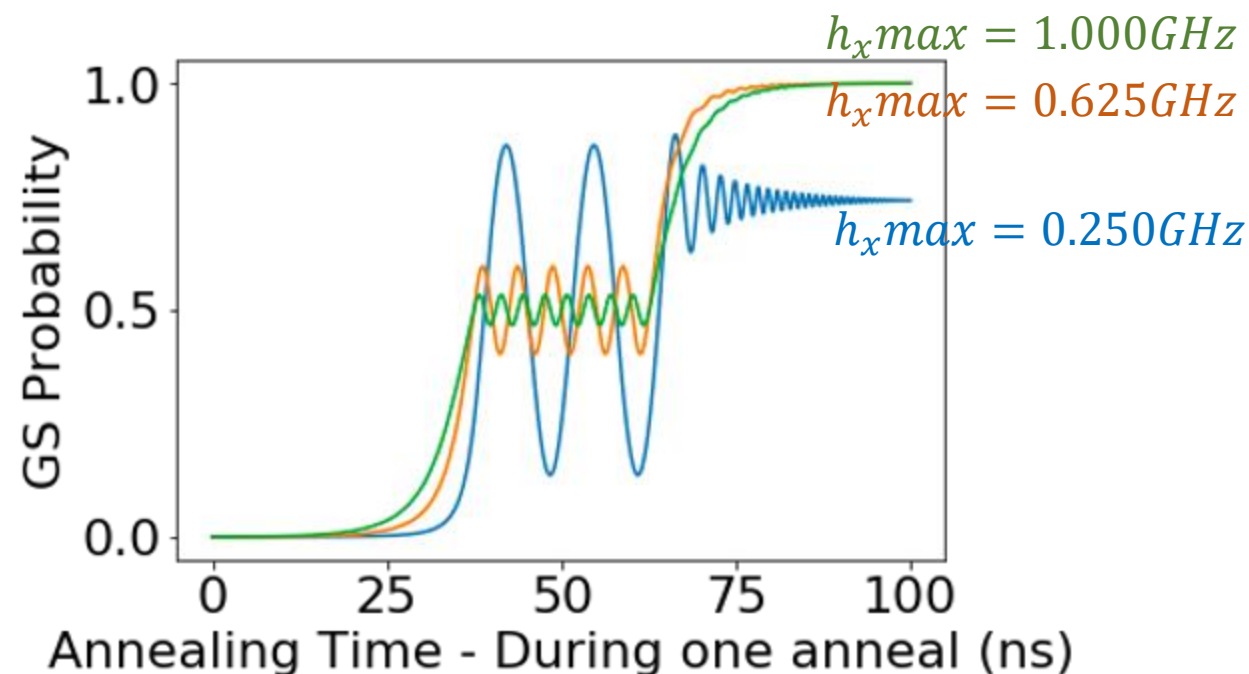
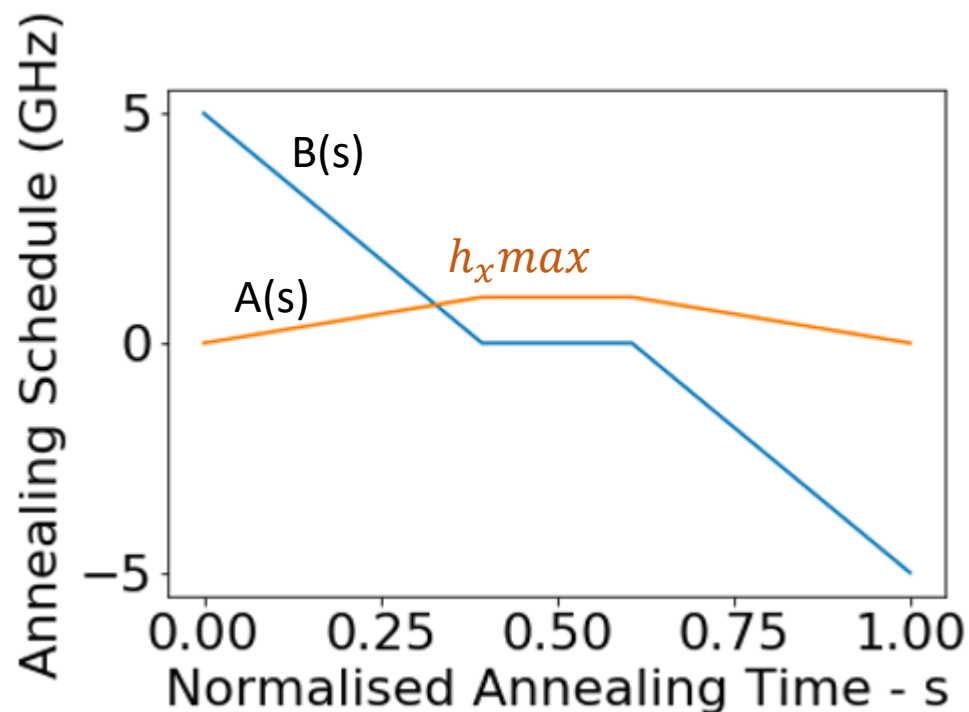
Hybrid Quantum Annealing and Continuous-time Quantum Walk

Hybrid Reverse Annealing and Continuous-time Quantum Walk

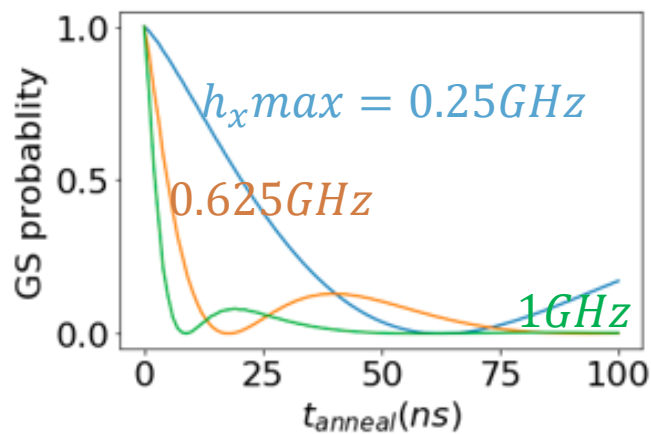
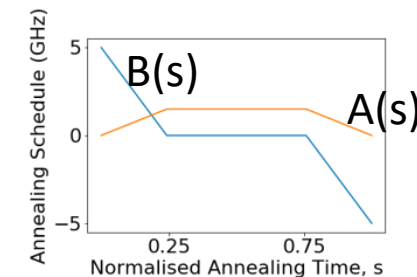
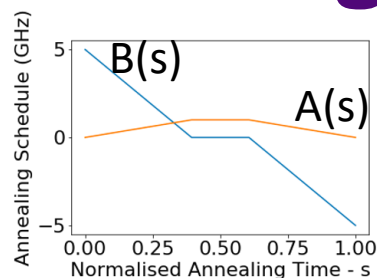
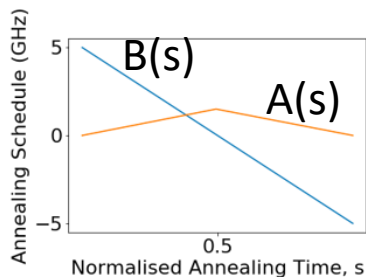
Proposed Experimental Set-up

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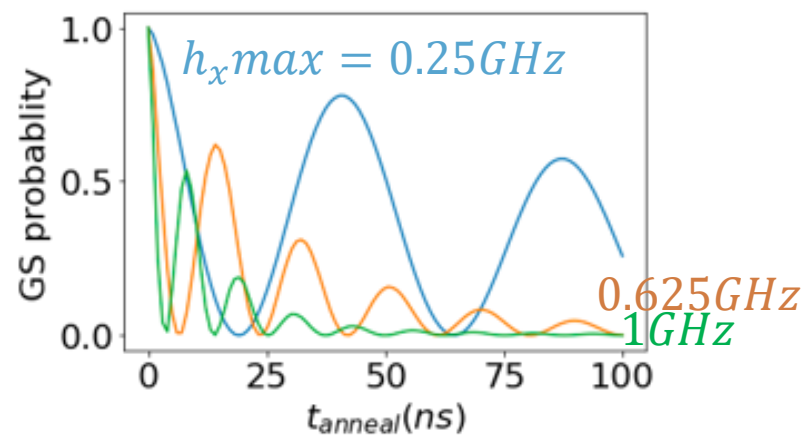
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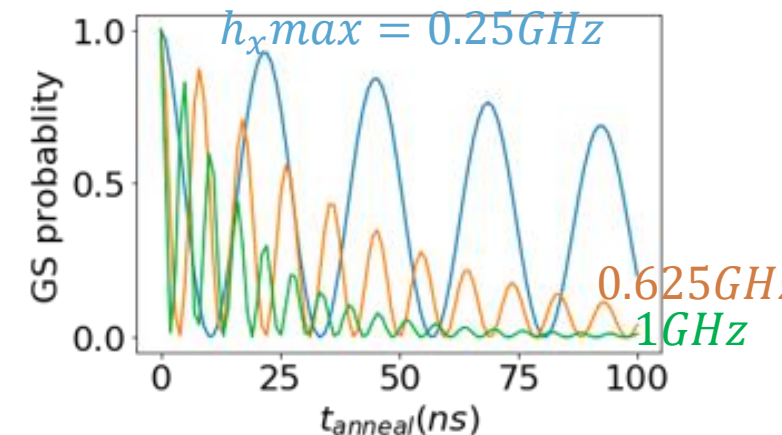
# Hybrid Reverse Annealing and Continuous-time Quantum Walk – Single Qubit



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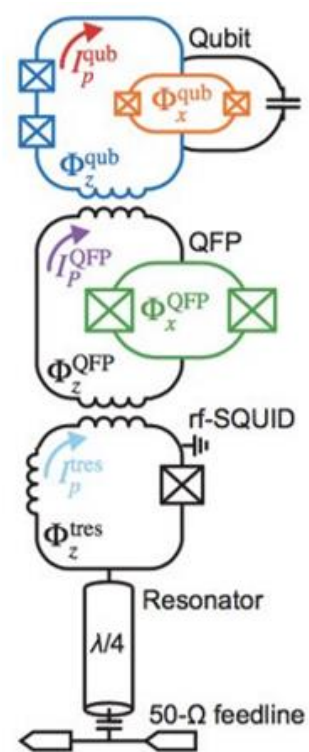
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# Experimental Proposal- *Jeffrey A. Grover et al*



# Conclusion

- For both pre-walk forward and reverse anneals, **small transverse field (0.25GHz)** shows **largest amplitude** of oscillation **within the walk**.
- For both pre-walk forward and reverse anneals, **longer walks** lead to **increased oscillations** with **larger amplitudes**.
- The time scale and frequency of oscillations for these schedules suggest the ability to verify this **experimentally** using **high coherence qubits**.



**Thank you**