From Classical Controls to Quantum Gates

Introduction into the Calibration of Superconducting Qubits

Ibraheem AlYousef, UMQ

From Classical Controls to Quantum Gates

Introduction into the Calibration of Superconducting Qubits

1. Quantum Computing Background
2. Calibration Methods
3. Simulation Verification

From Classical Controls to Quantum Gates

Introduction into the Calibration of Superconducting Qubits

By the end of this workshop, you will learn to:

- Calibrate an X gate on a superconducting device.
- Use QuTiP to simulate different calibration routines.

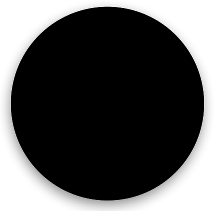
QR for Notebook

Quantum Computing Background

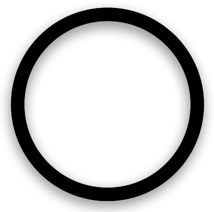
Quantum Computing

Classical Computing

Deterministic



"OR"



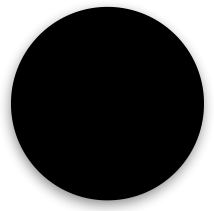
Binary Language

10001 + 110100 = 1000101

Quantum Computing

Classical Computing

Deterministic



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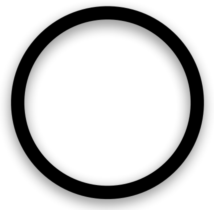

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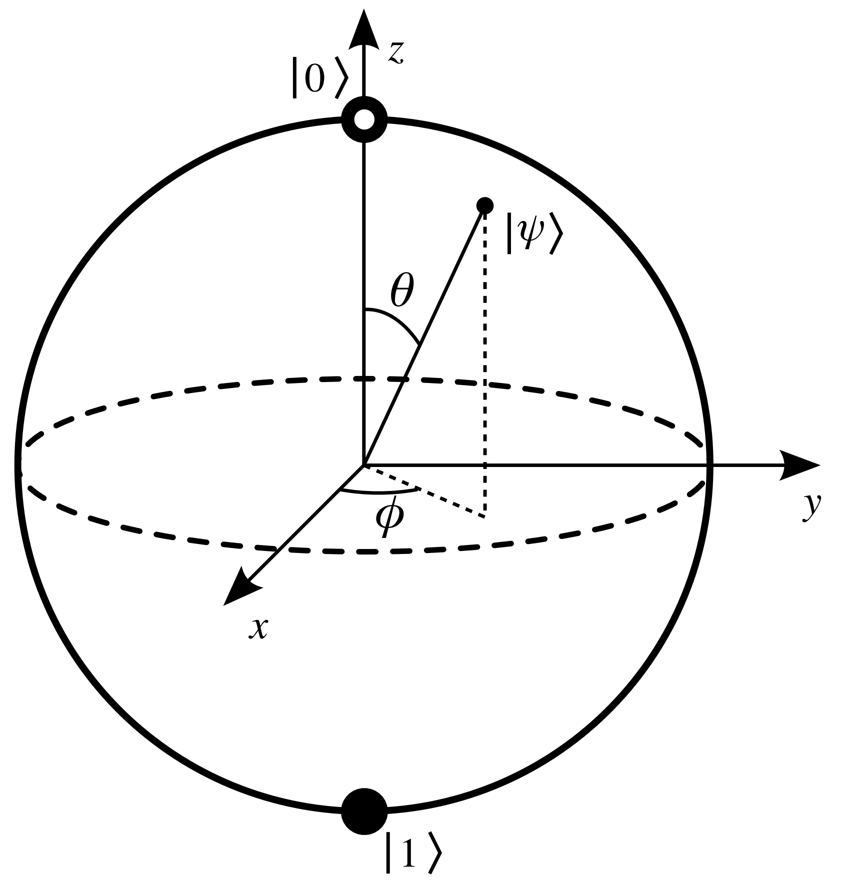
Quantum Computing

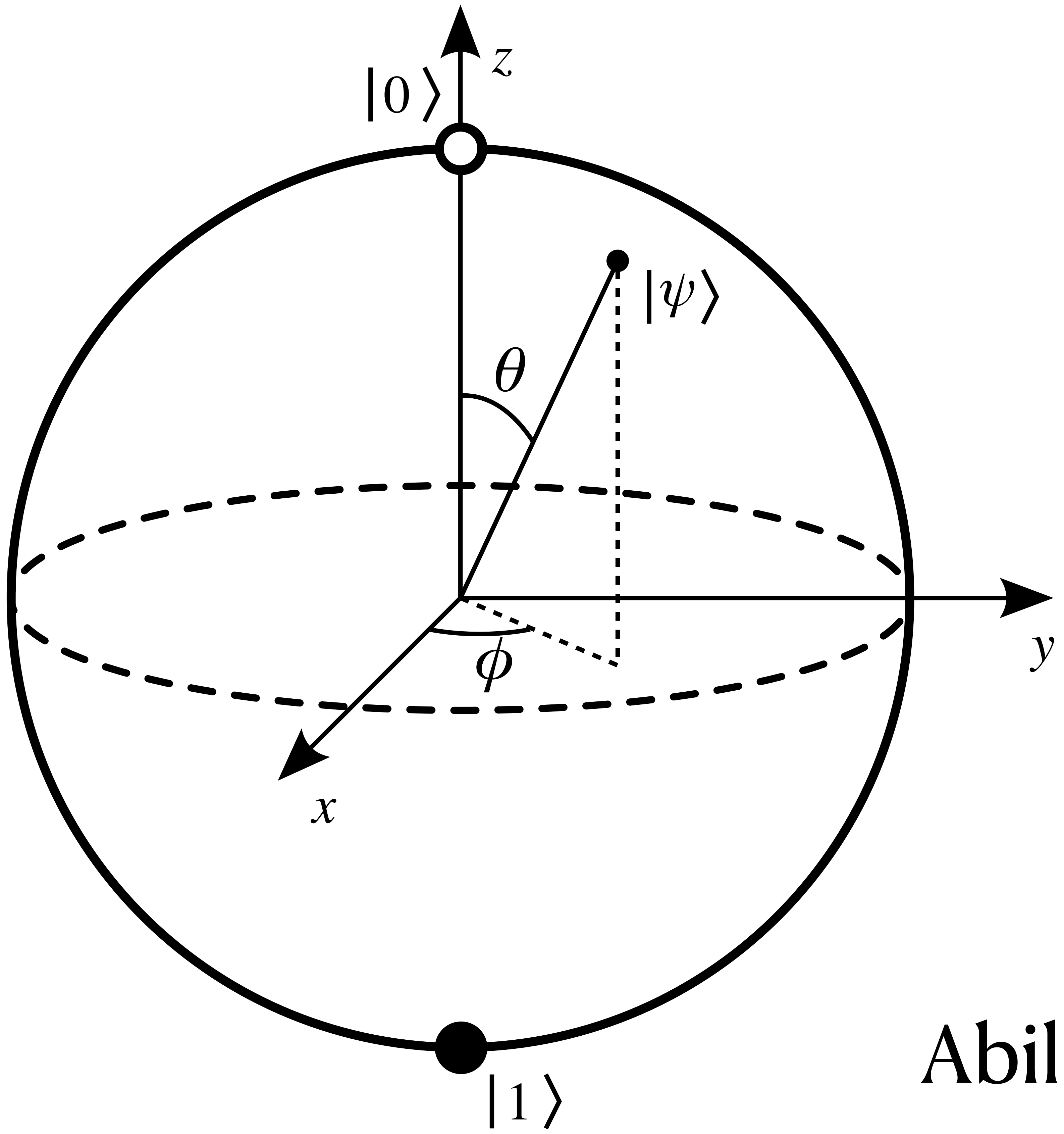
Probabilistic



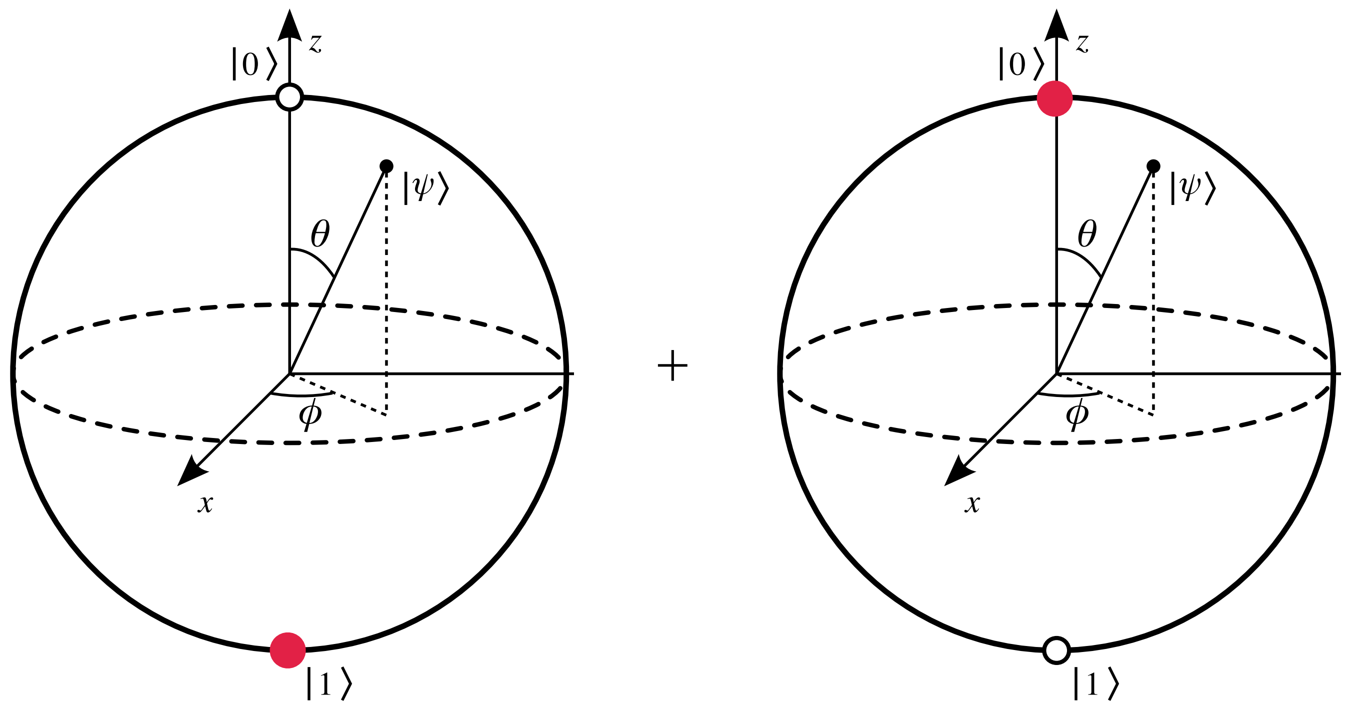
Linear Algebra

$$\begin{pmatrix}1\\0\end{pmatrix}+\begin{pmatrix}0\\1\end{pmatrix}=\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}$$

Quantum Computing

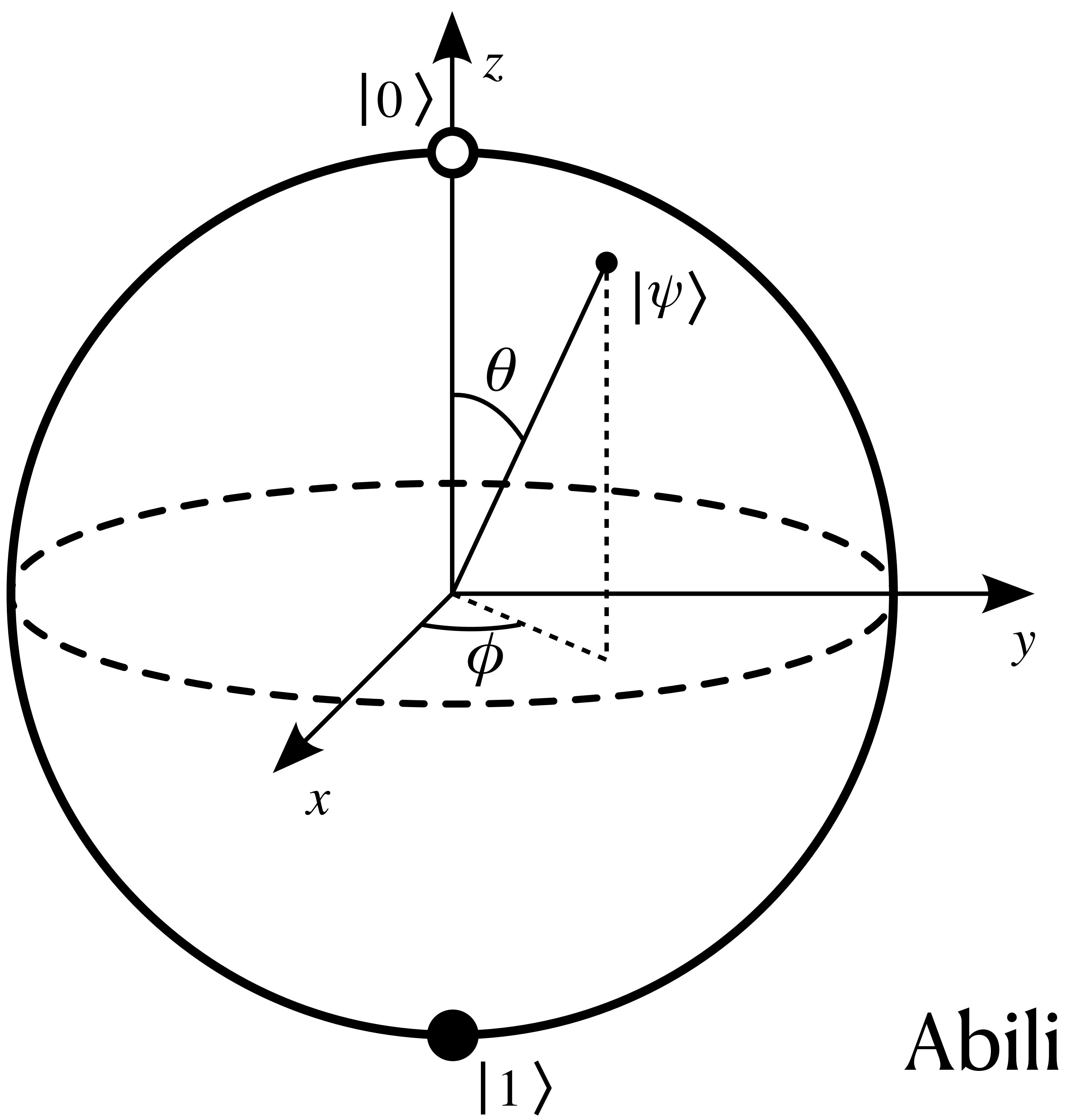


○ Superposition

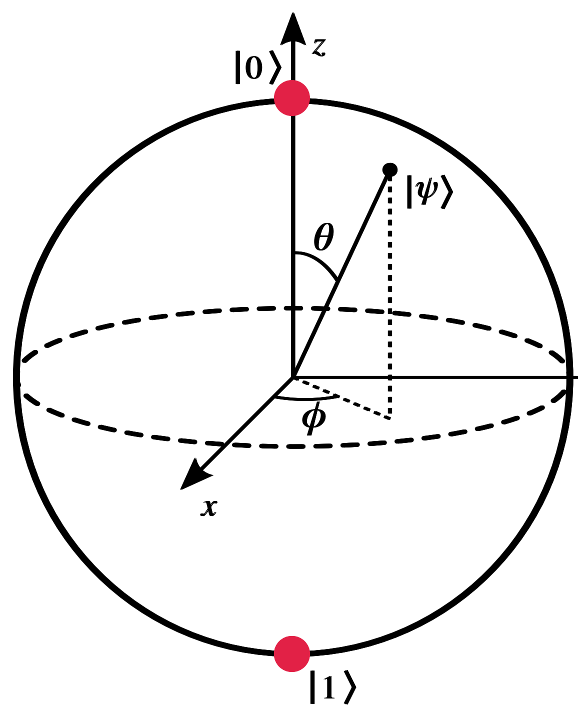


Ability to exist in multiple states

Quantum Computing



○ Superposition



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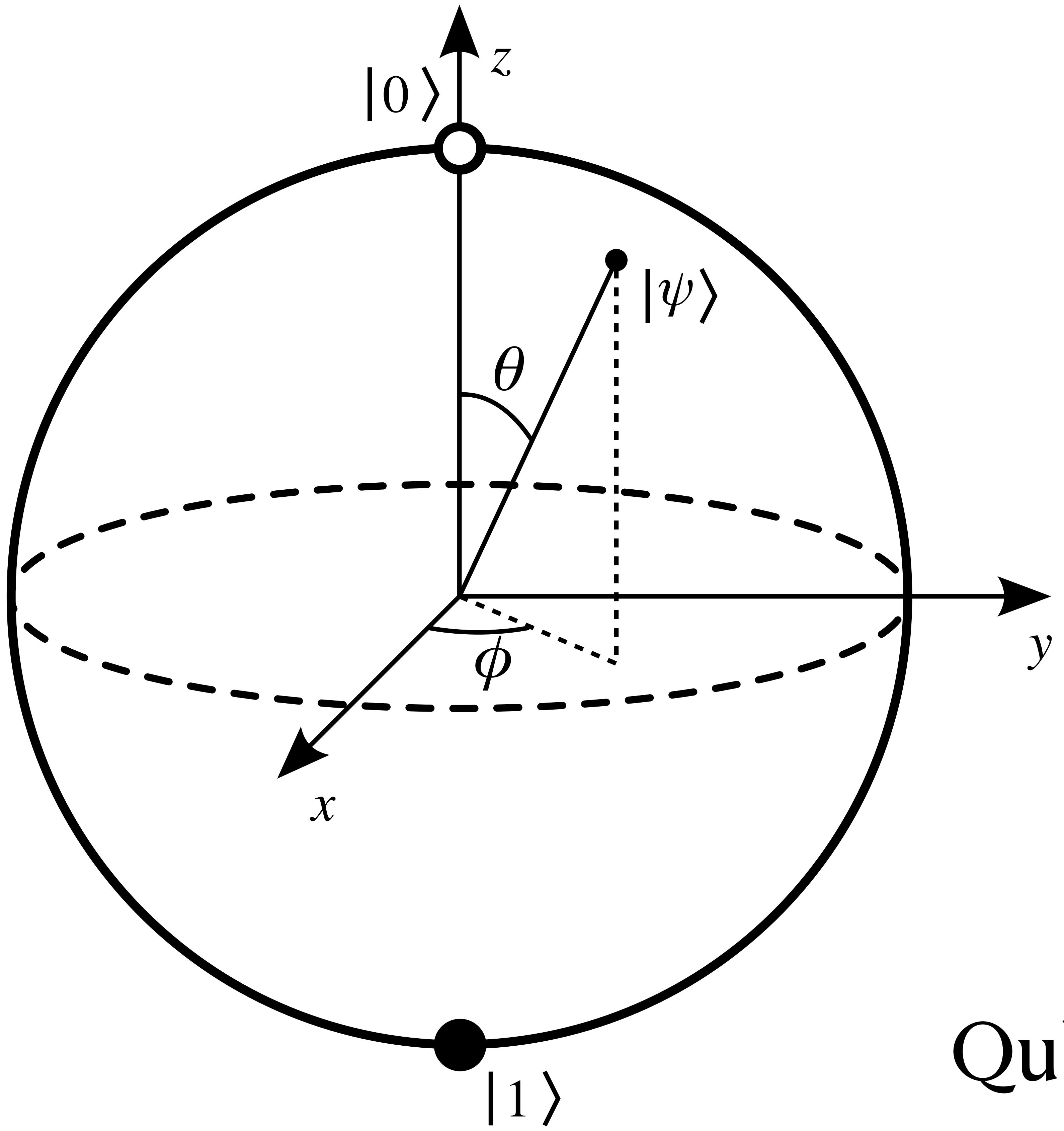
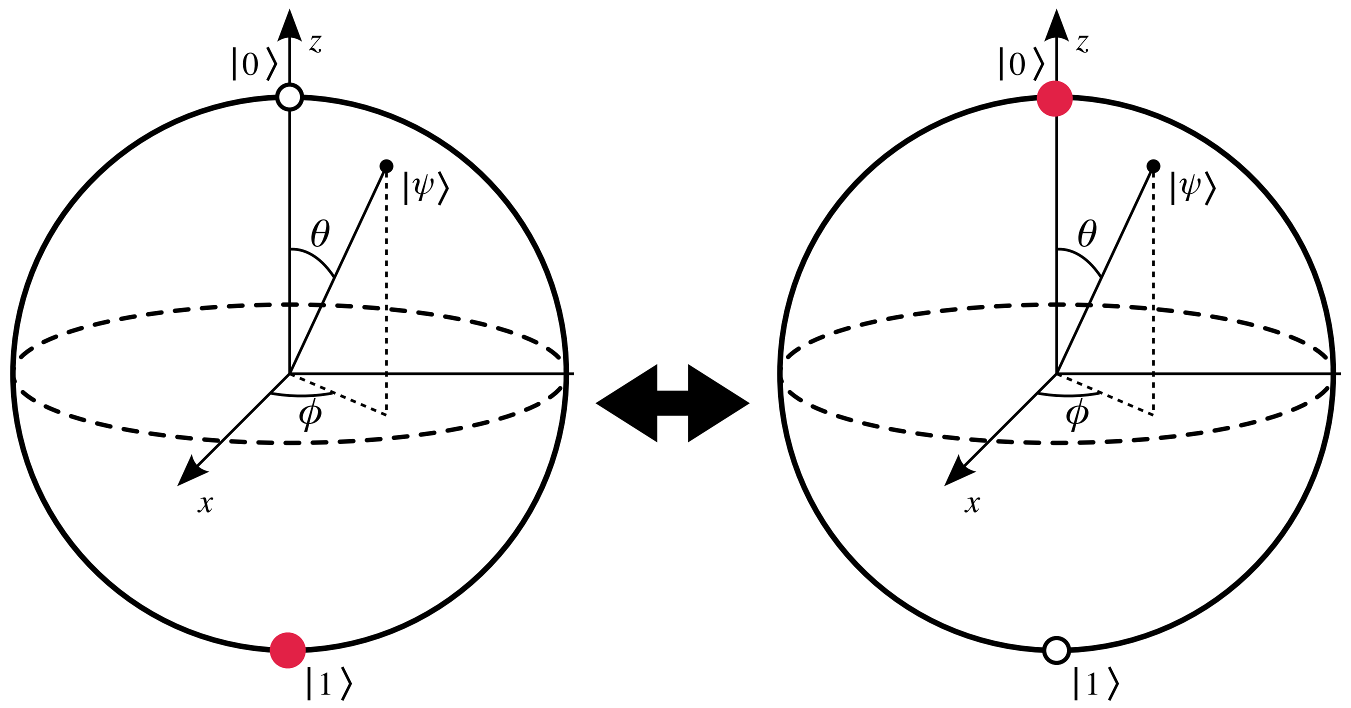
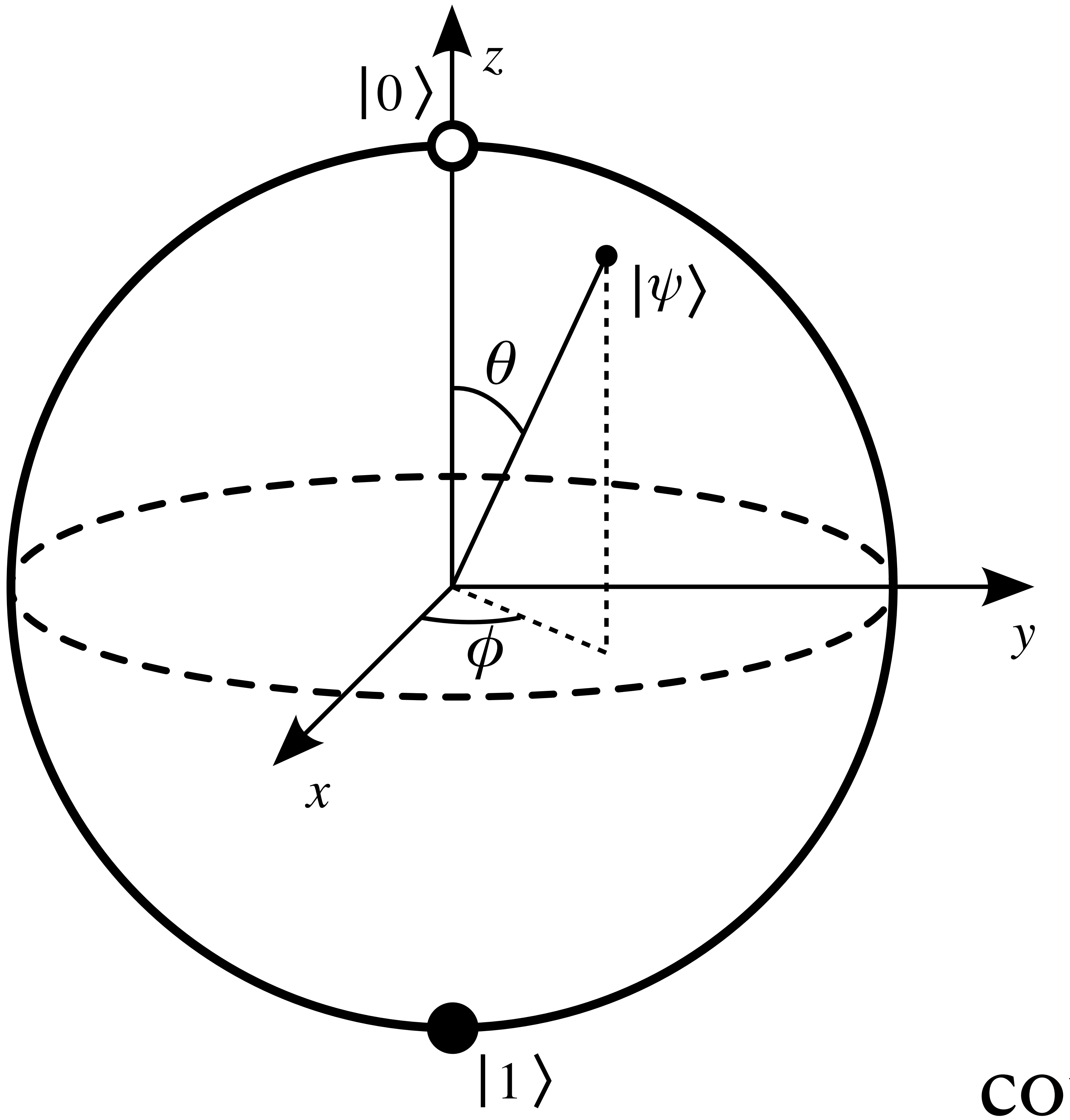


○ Interference

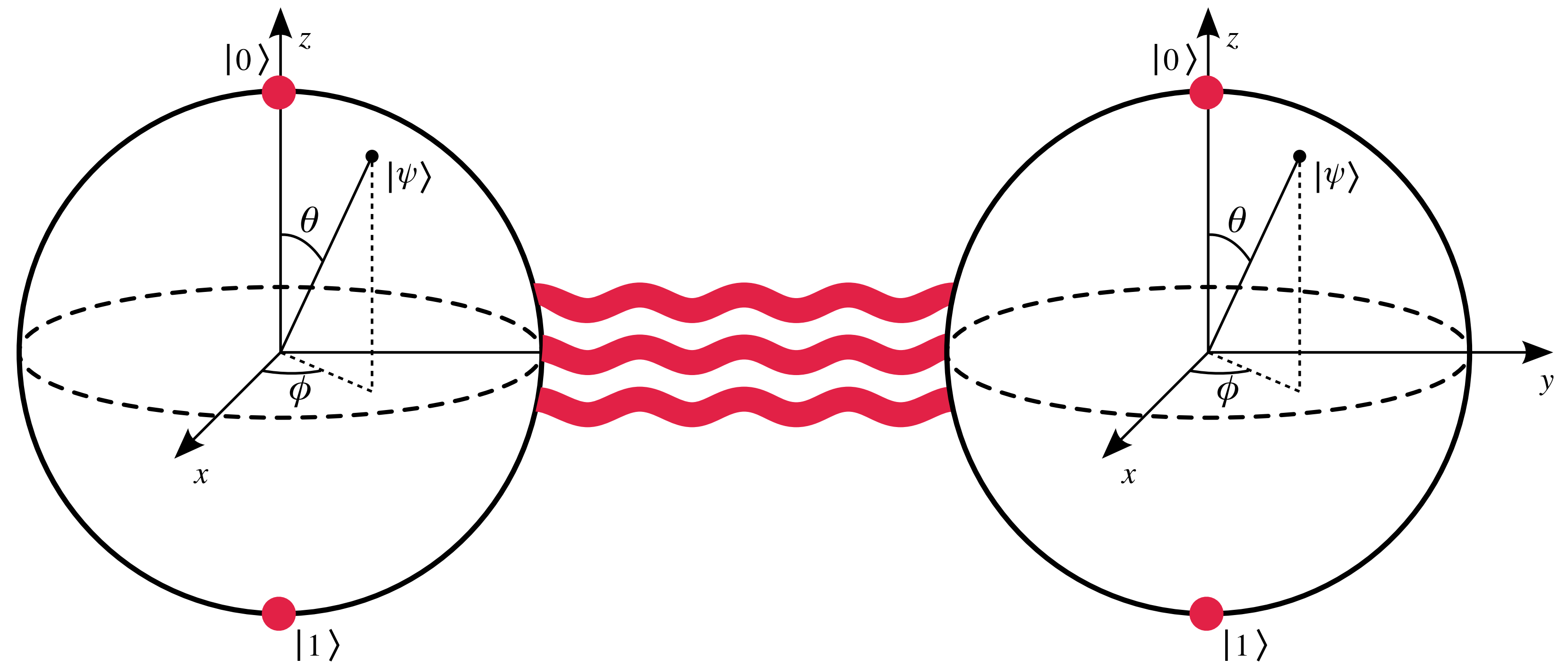


Qubits can affect one another

Quantum Computing

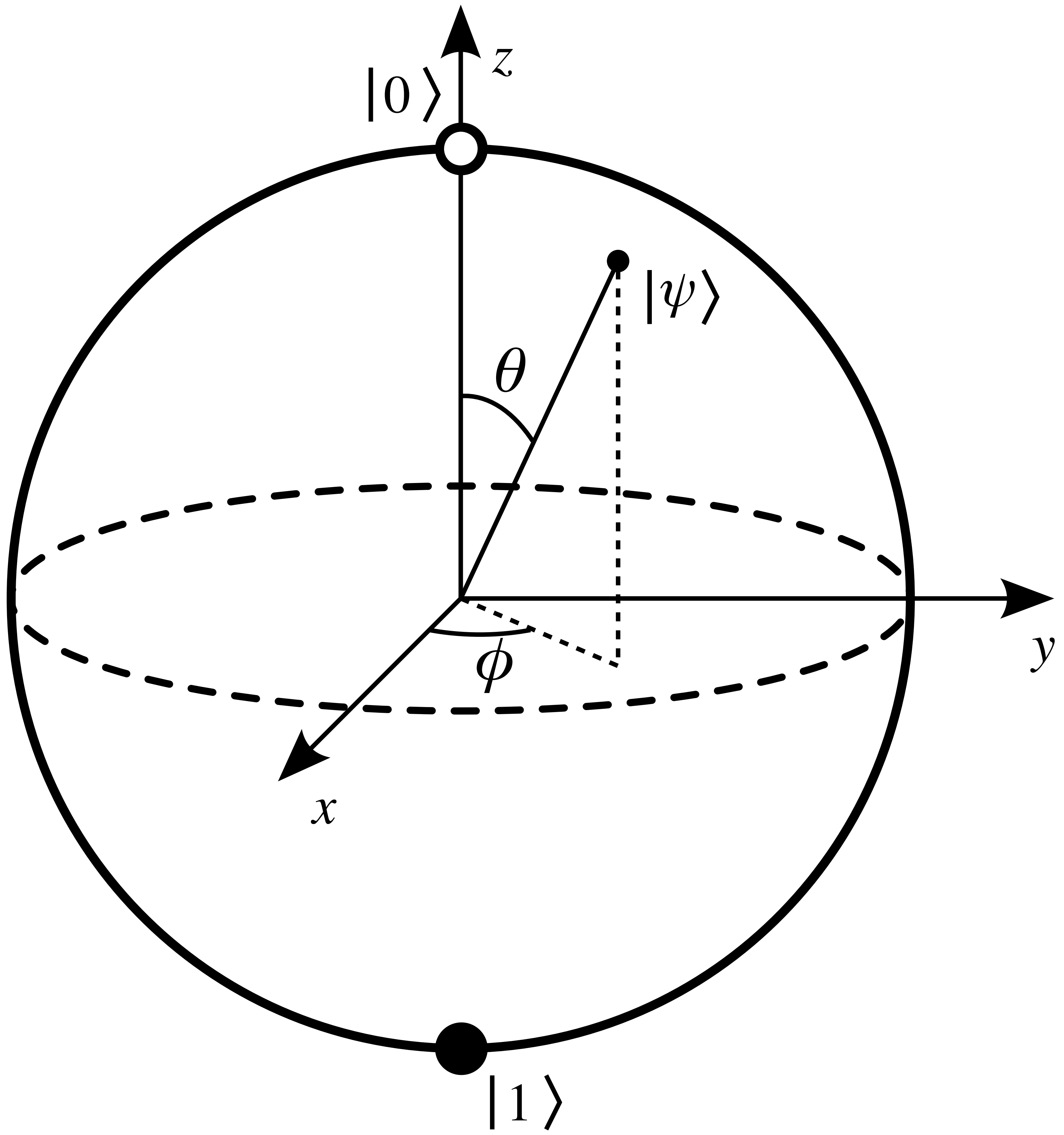


- Entanglement



Inability to describe constituents independently

Quantum Computing



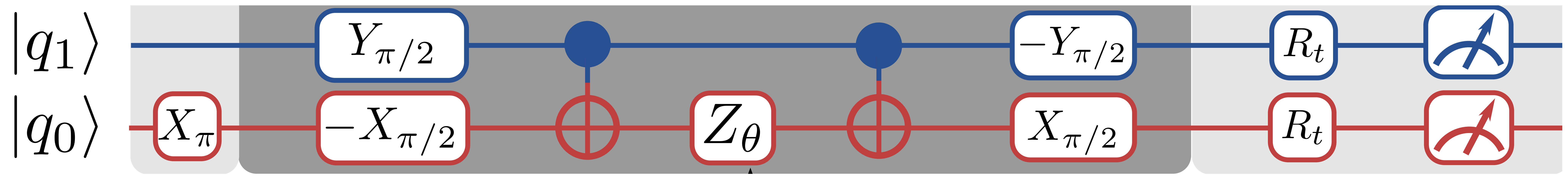
○ Measurement

Quantum Computing

- Measurement

The collapse into classical bits

Quantum Information Processing



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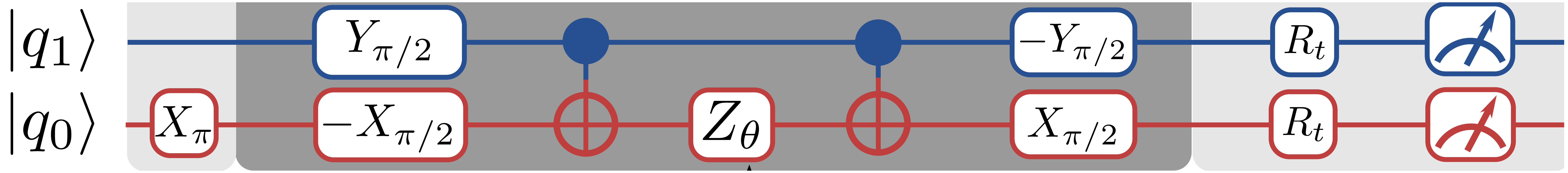

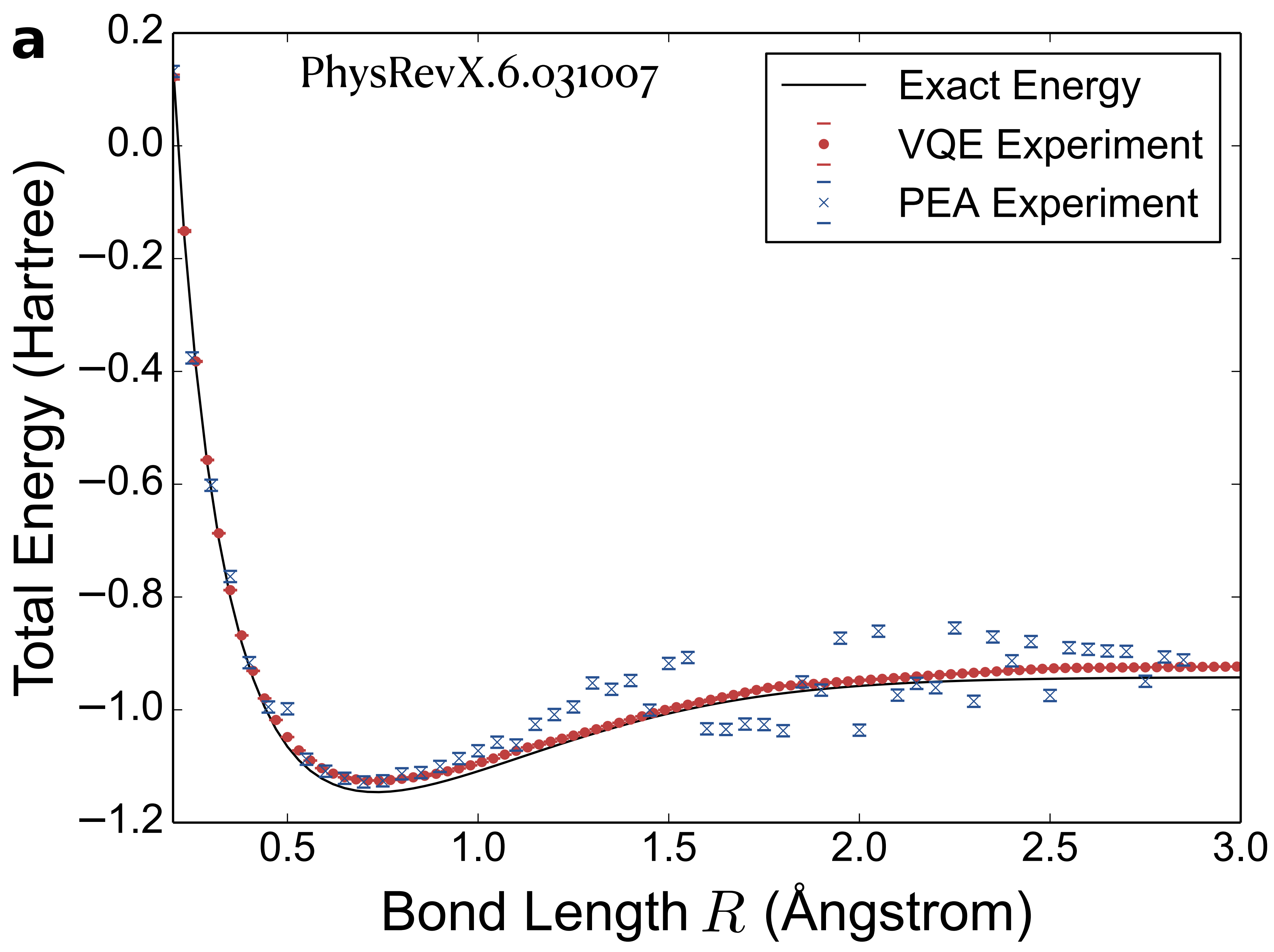

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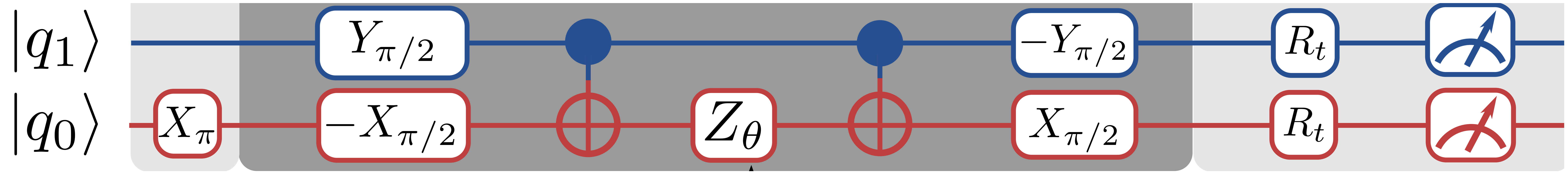

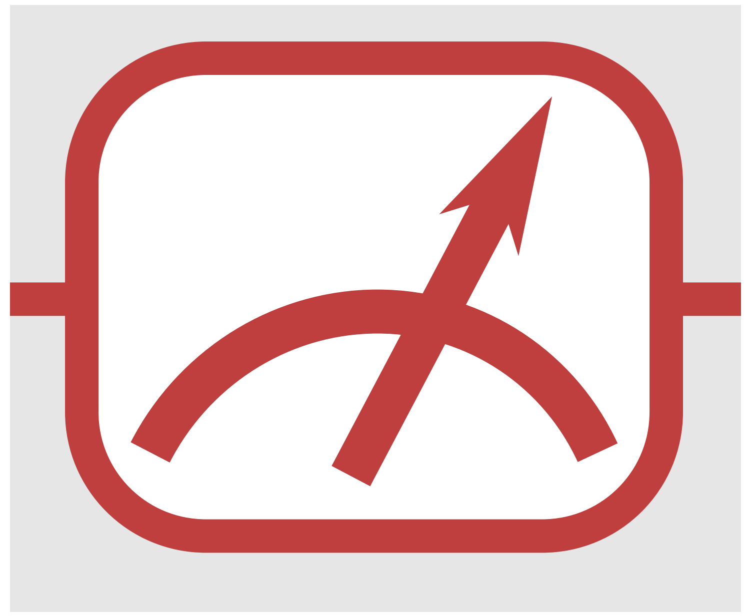

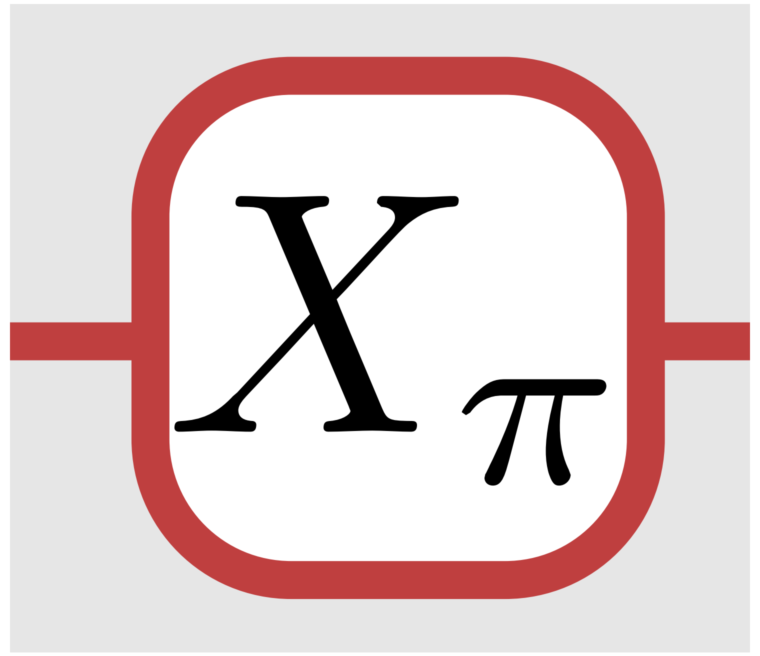

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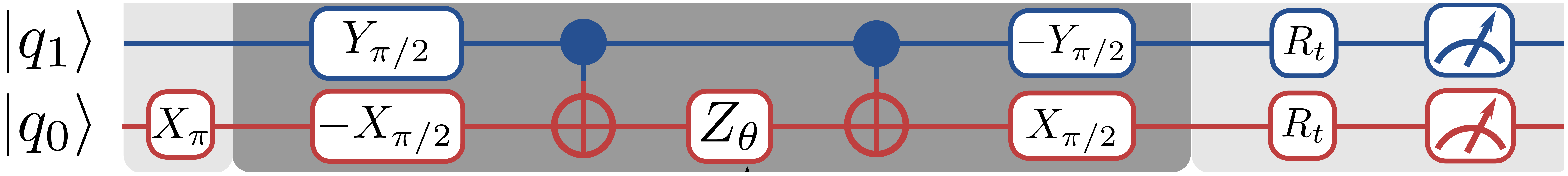
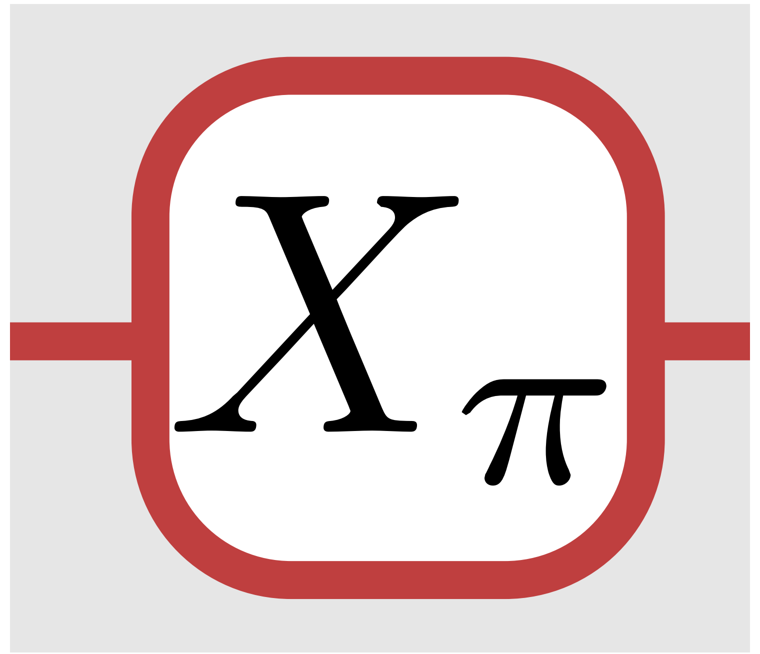


How to measure the quantum state?

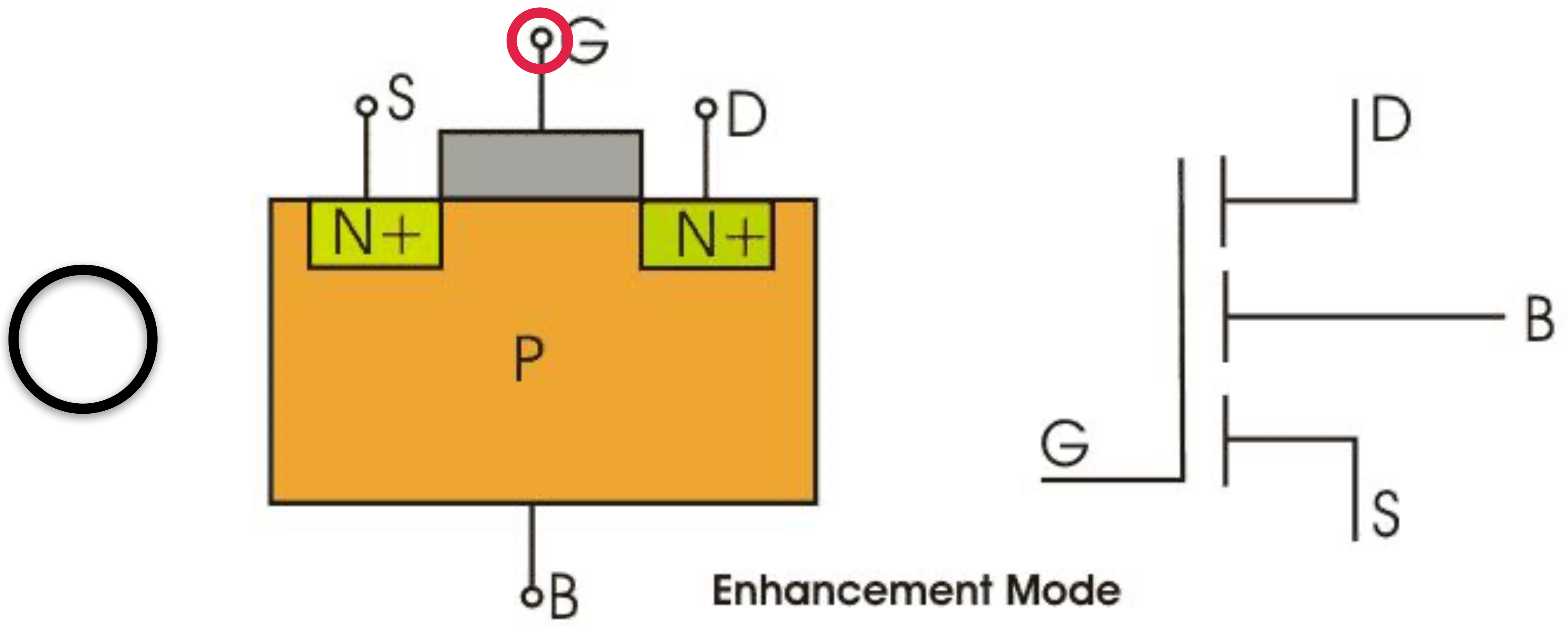


How to apply X gate?

Physical Realization

Classical Bit (MOSFET)

"OFF"



Physical Realization

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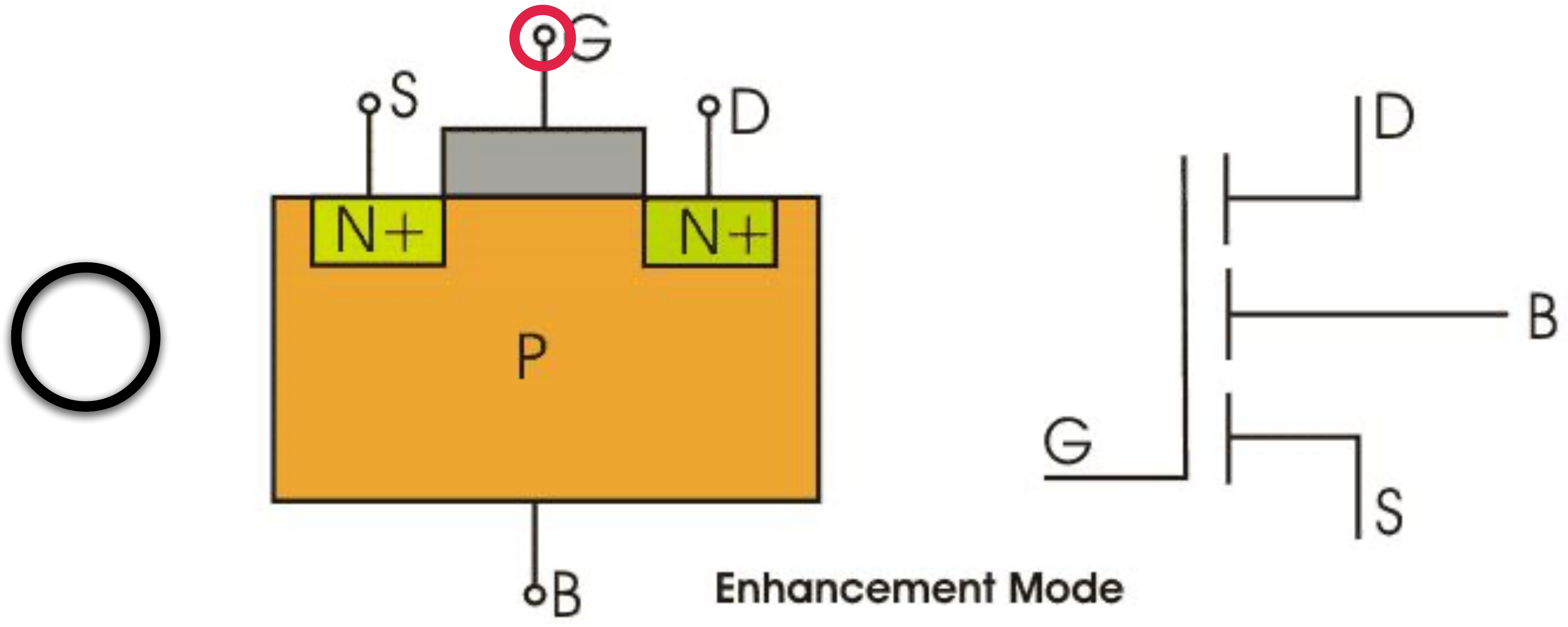

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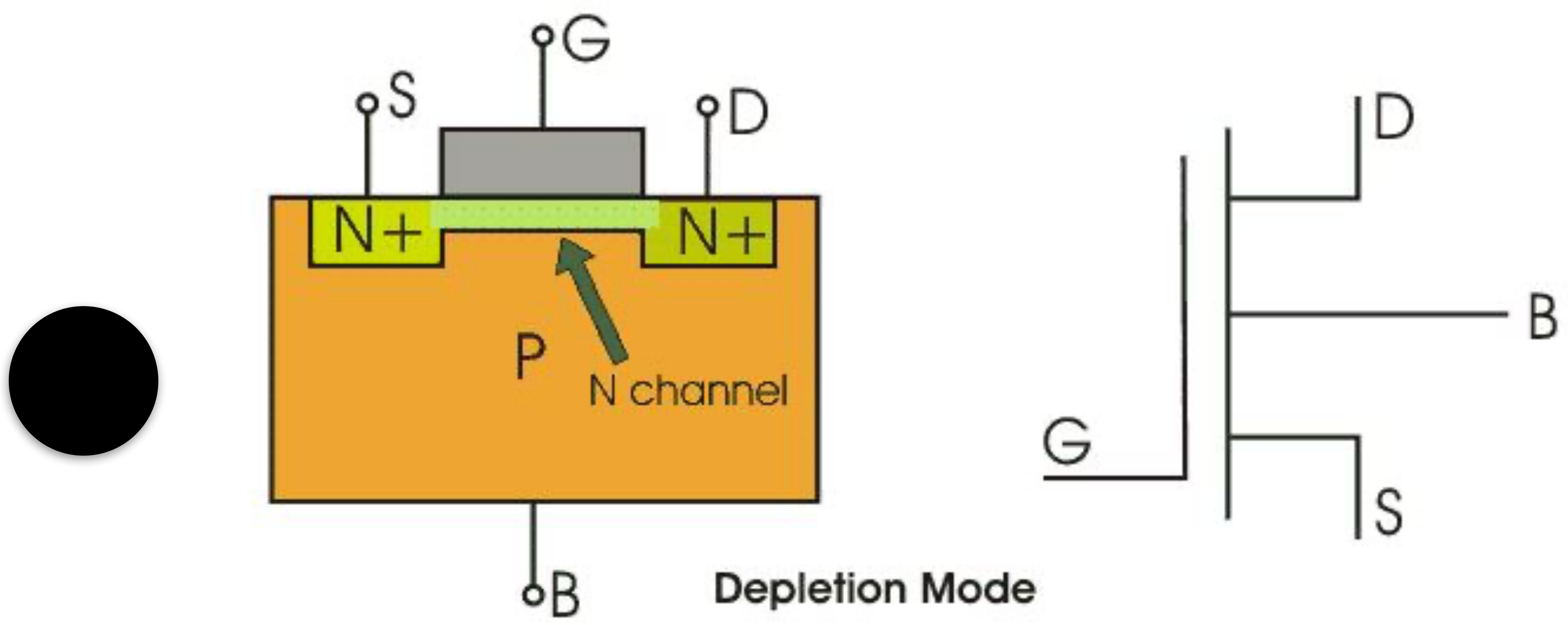

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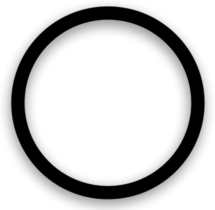

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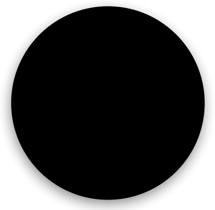
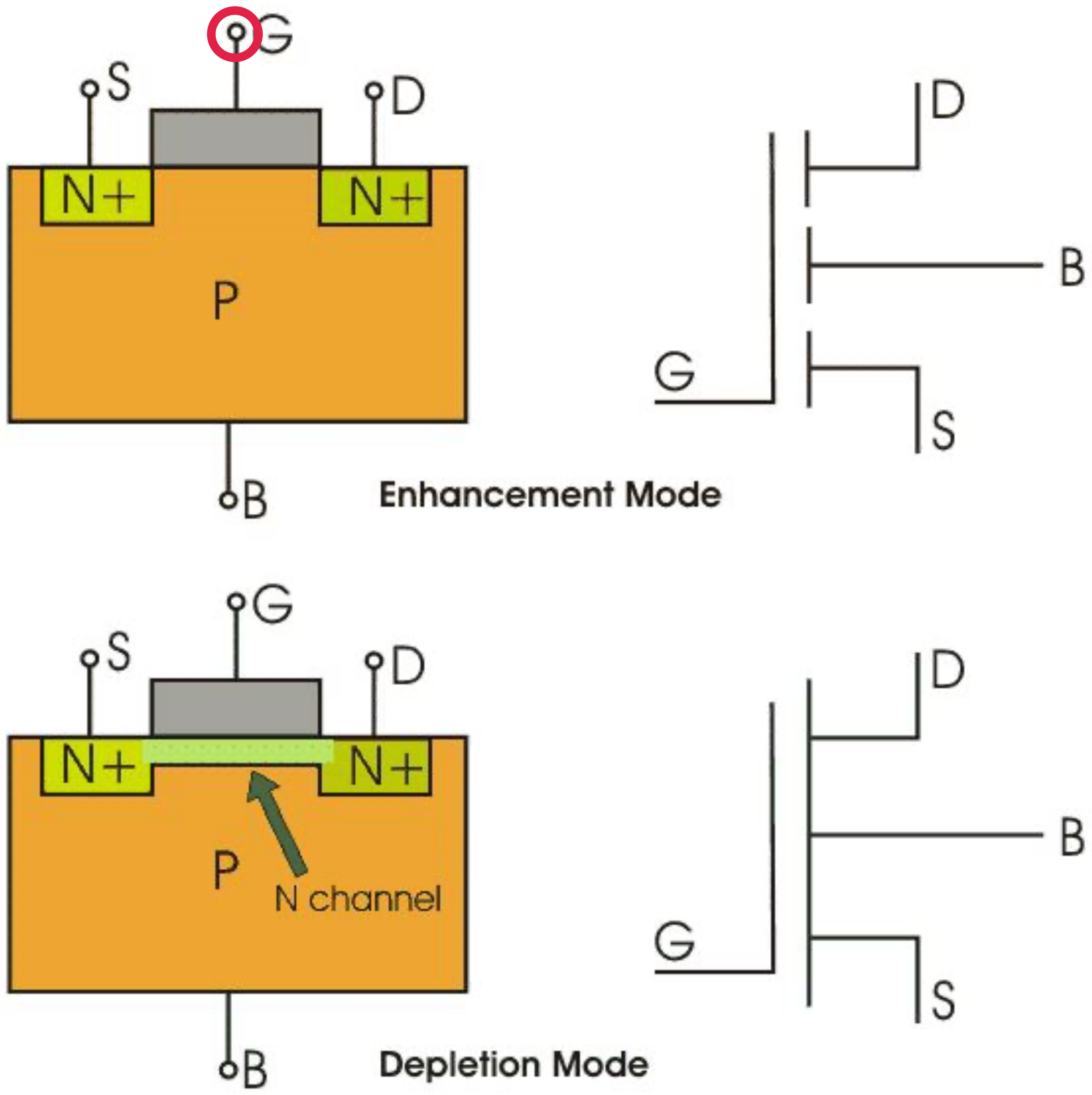
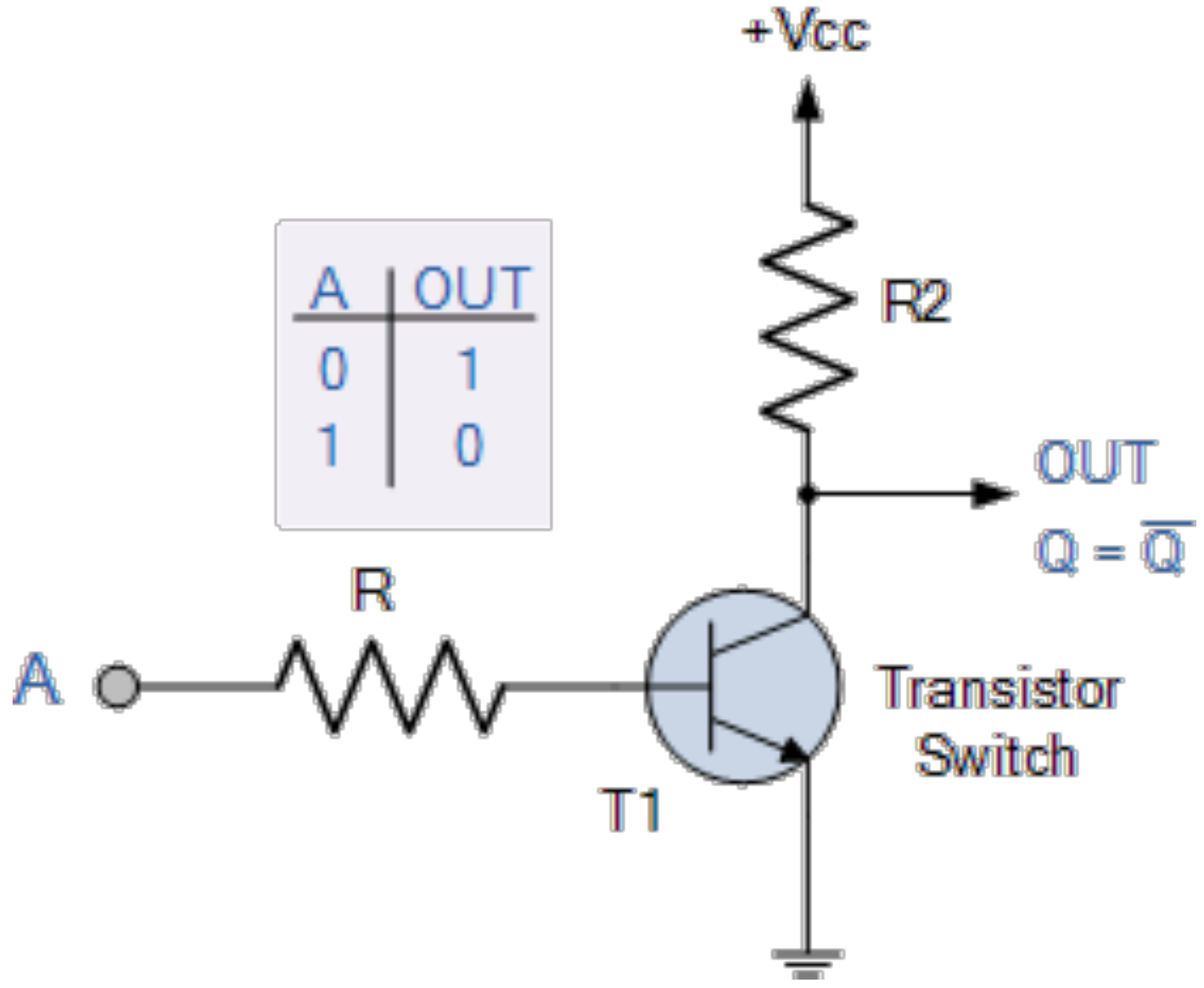




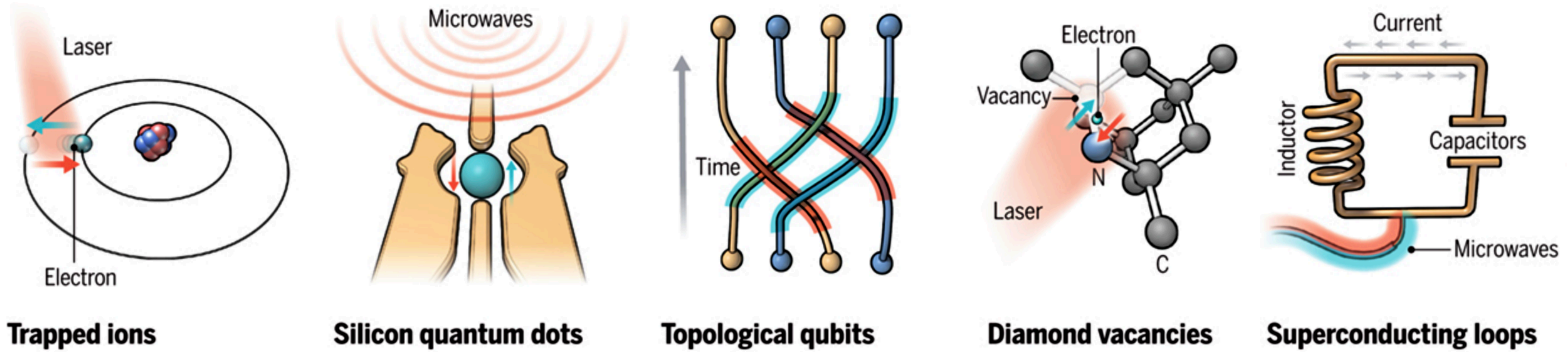


Classical NOT

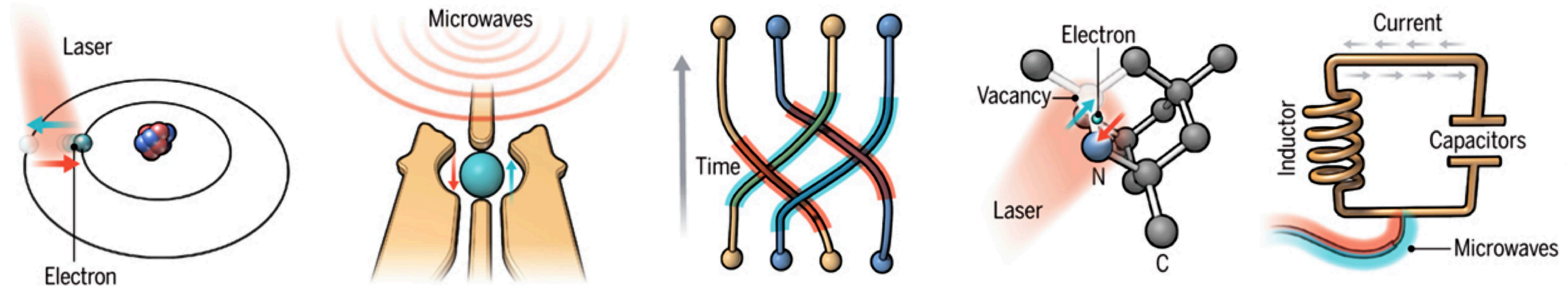
Physical Realization

What about the Qubit?

Qubit Platforms



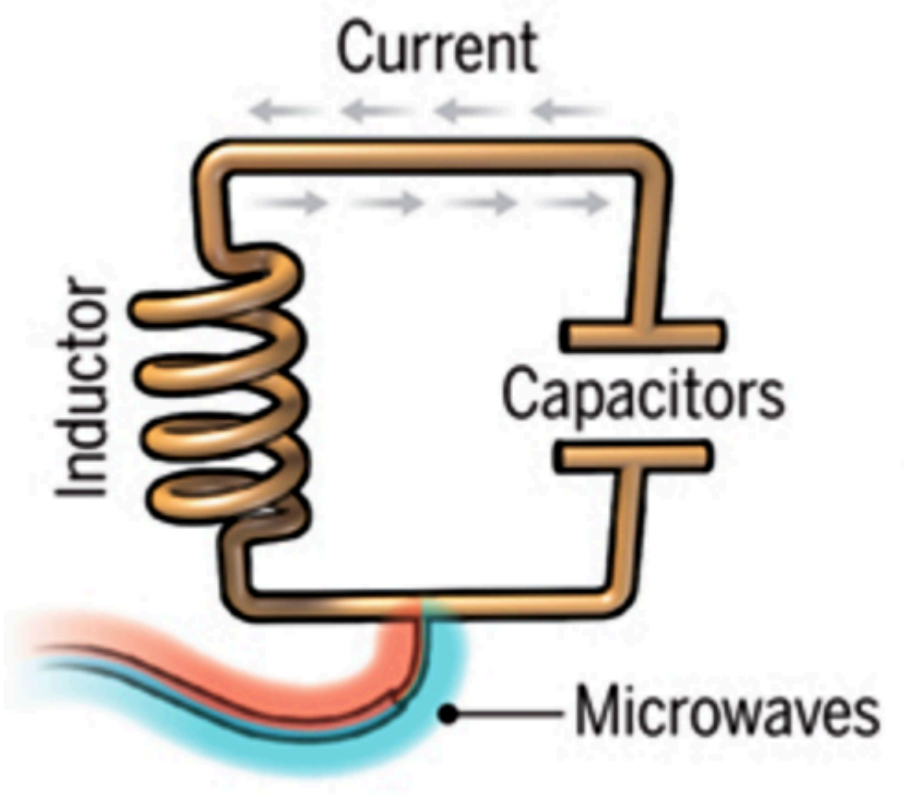
Qubit Platforms



Trapped ions **Silicon quantum dots** **Topological qubits** **Diamond vacancies** **Superconducting loops**

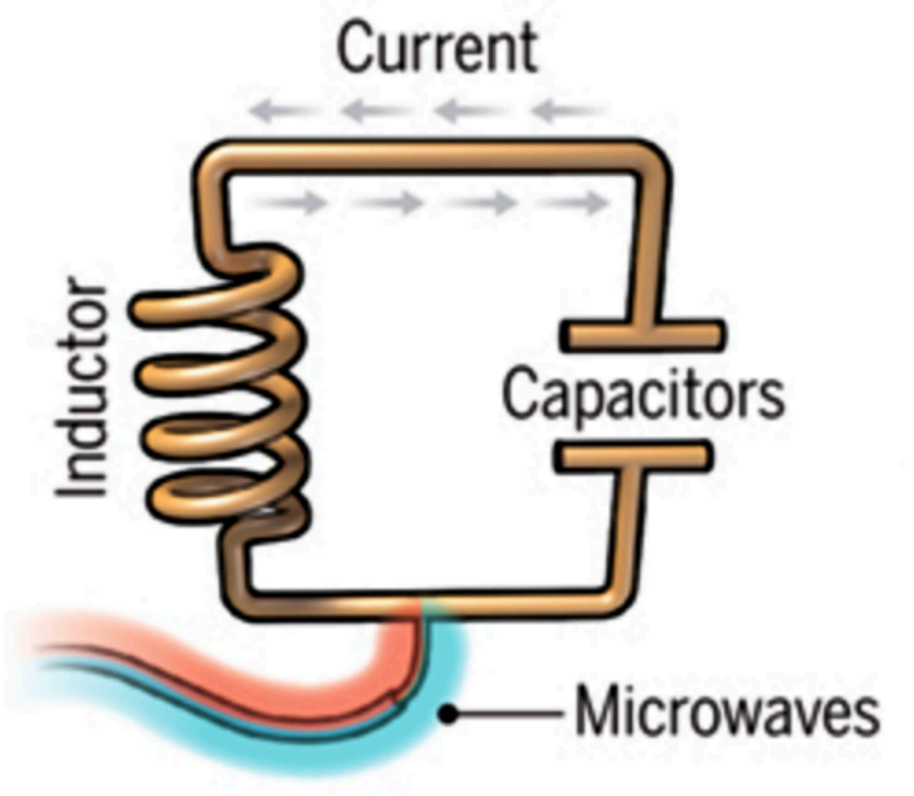
No Consensus Yet!

Qubit Platforms



Superconducting loops

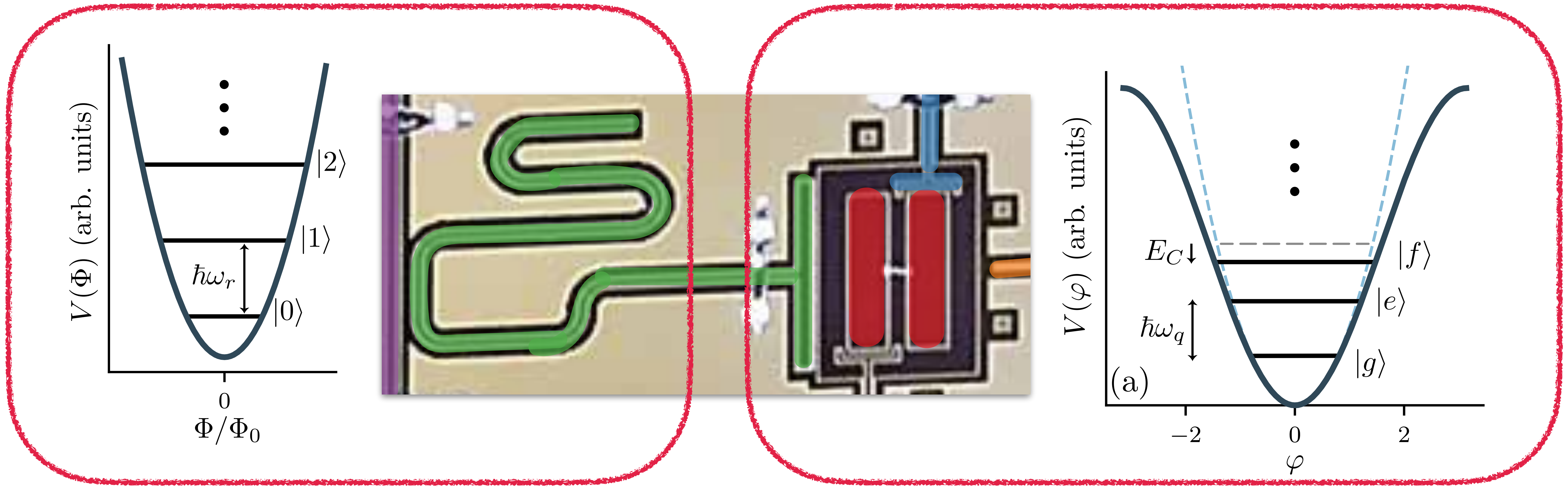
Qubit Platforms



Superconducting loops

Resonator

Transmon

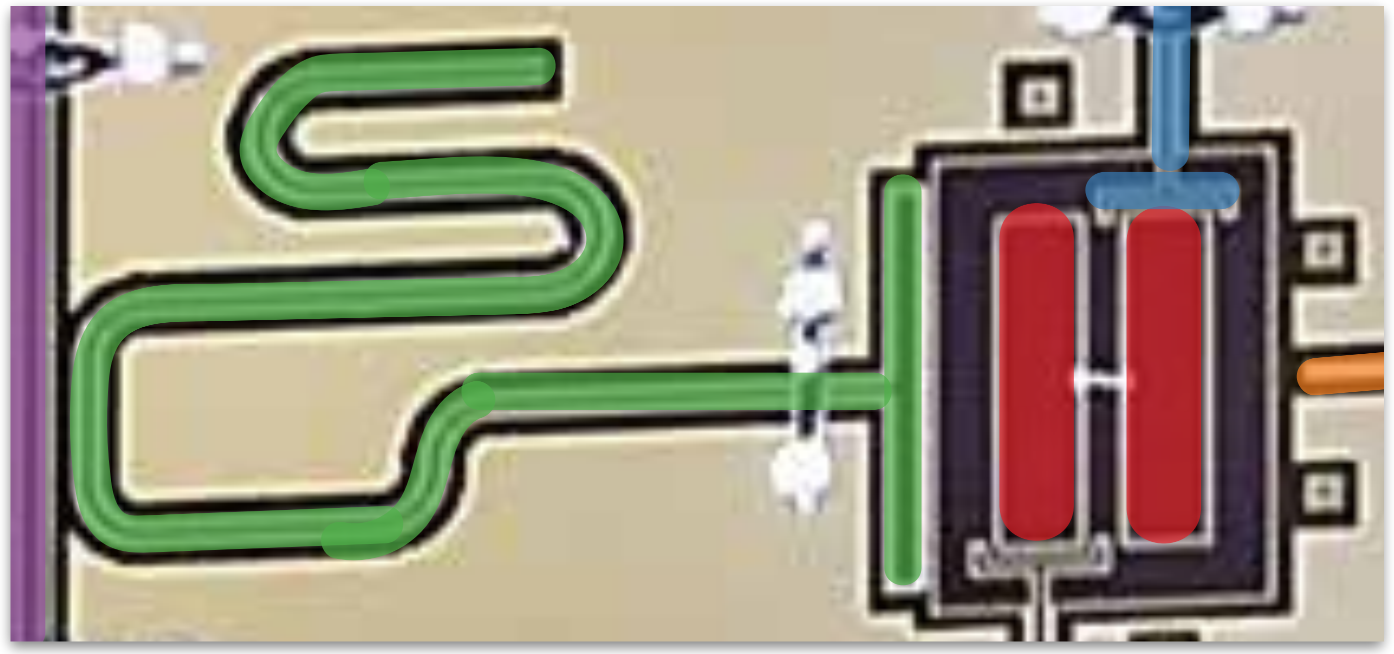


Measure / Read

Manipulate

Qubit Platforms

Using Microwave Signals!



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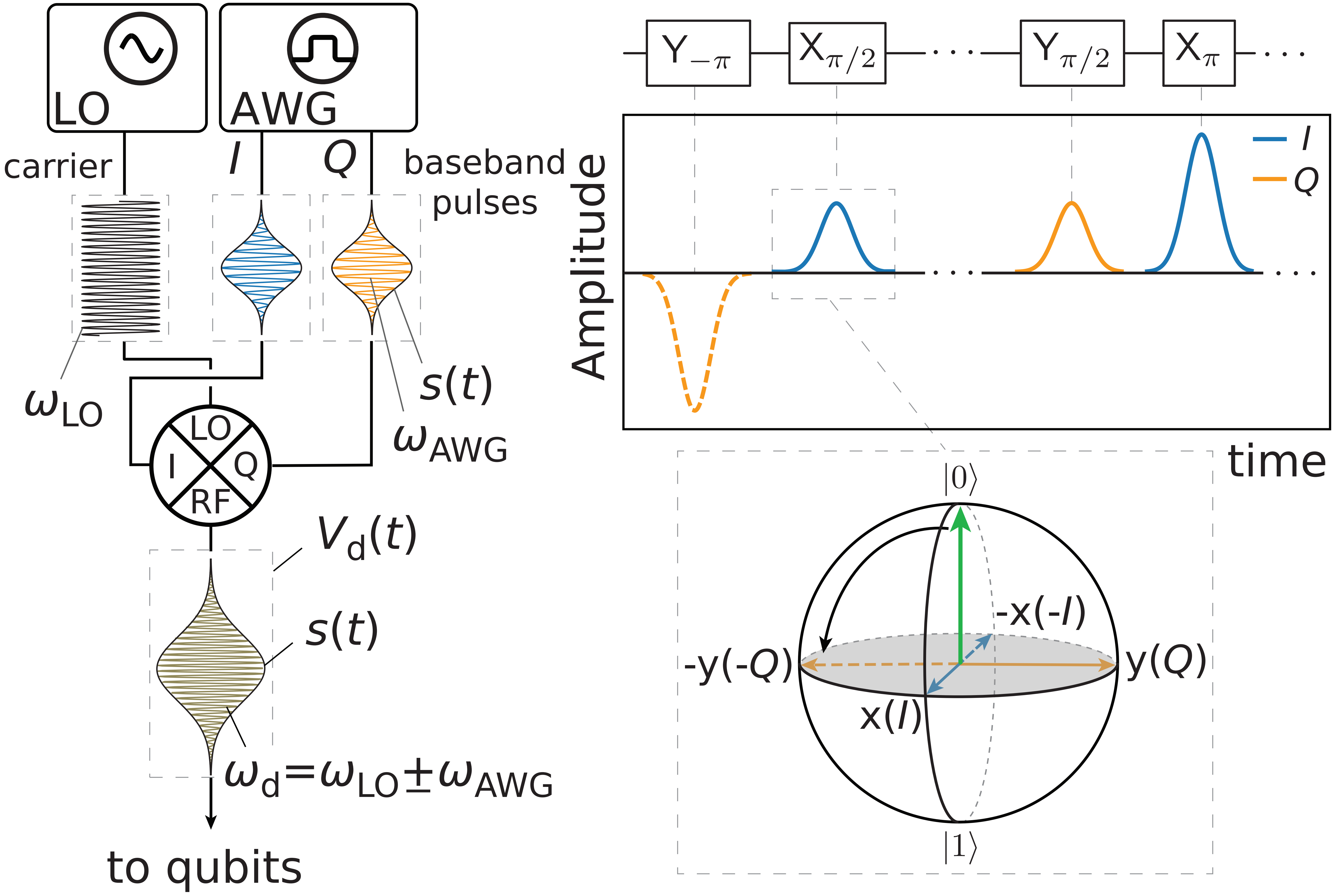

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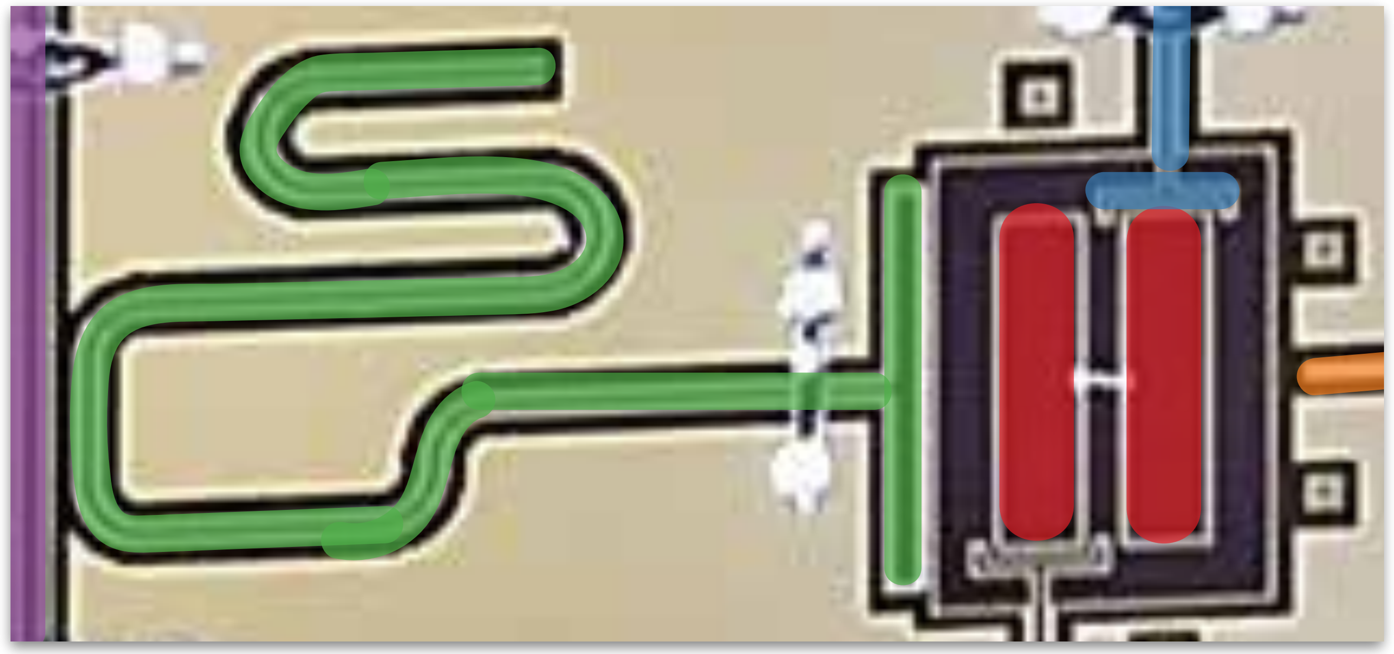

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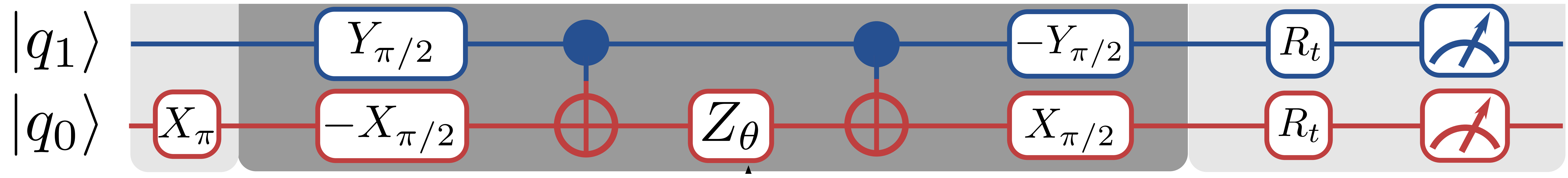

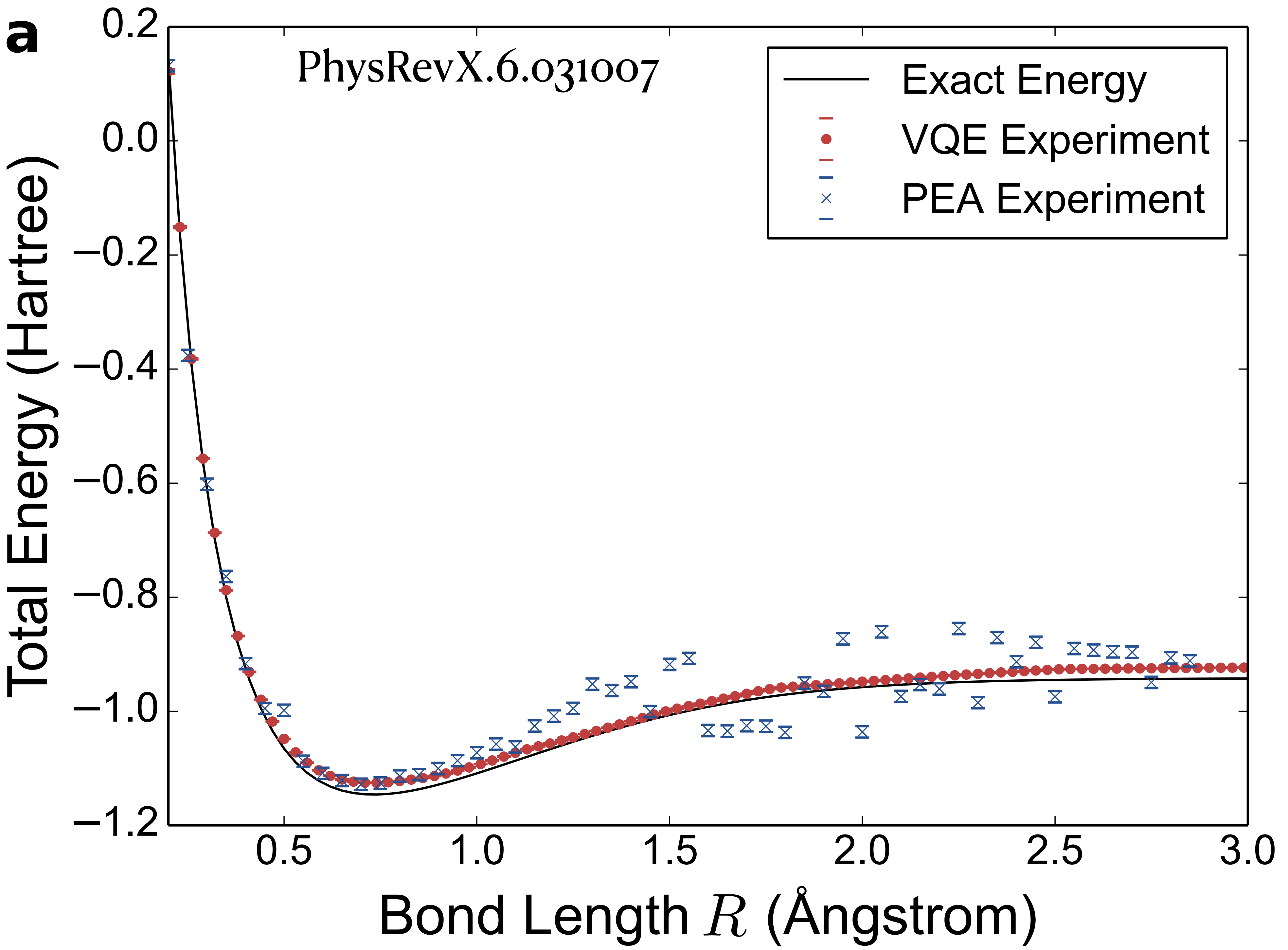

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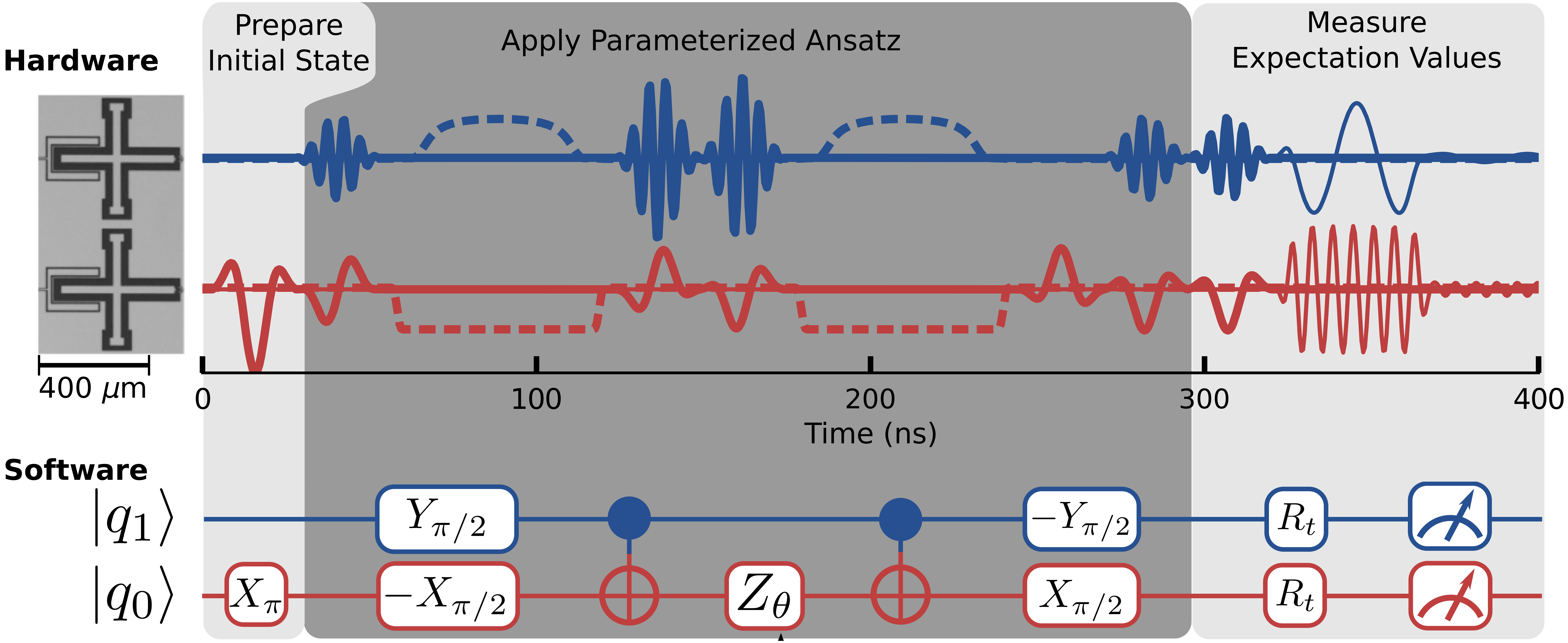


Qubit Calibrations

Qubit Calibration

Frequency-Domain:

- Resonator Spectroscopy
- Two-Tone Spectroscopy

Time-Domain:

- Rabi Measurement

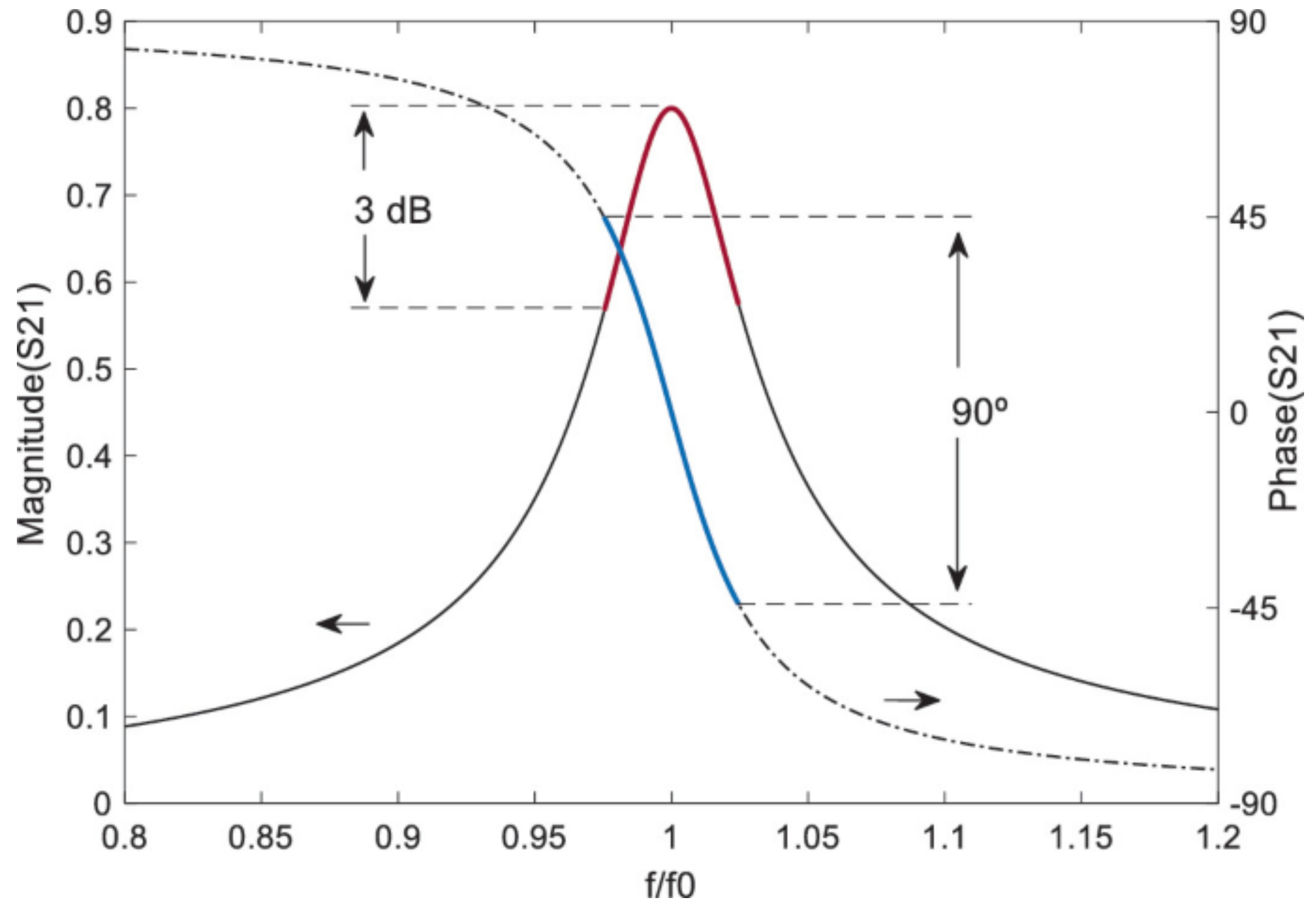
Characterization:

- T_1: Relaxation Time
- T_2^*: Dephasing Time

Resonator Spectroscopy

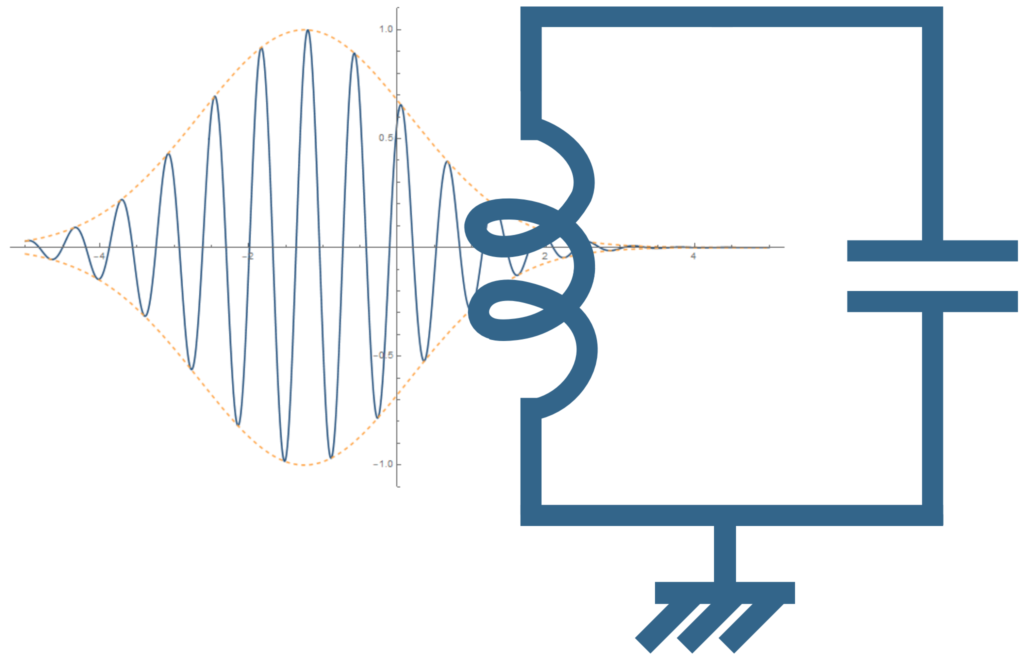
A Resonator is a device defined by its resonance frequency, it filter the signals that don't resonate with it.

Objective: Find the resonance frequency



How?

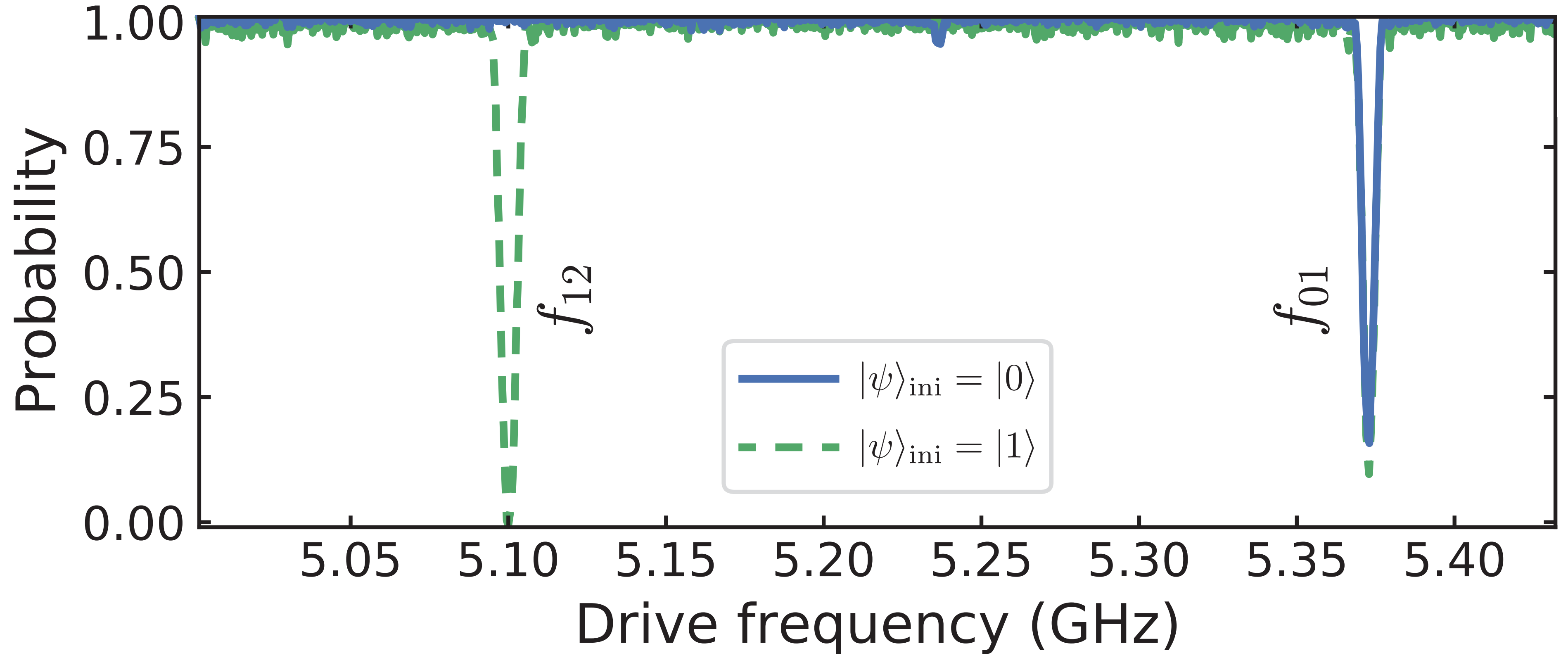
- Sweep a the frequency sent to the resonator.
- Measure the resonator response.
- The peak represents the resonance frequency.



Two-Tone Spectroscopy

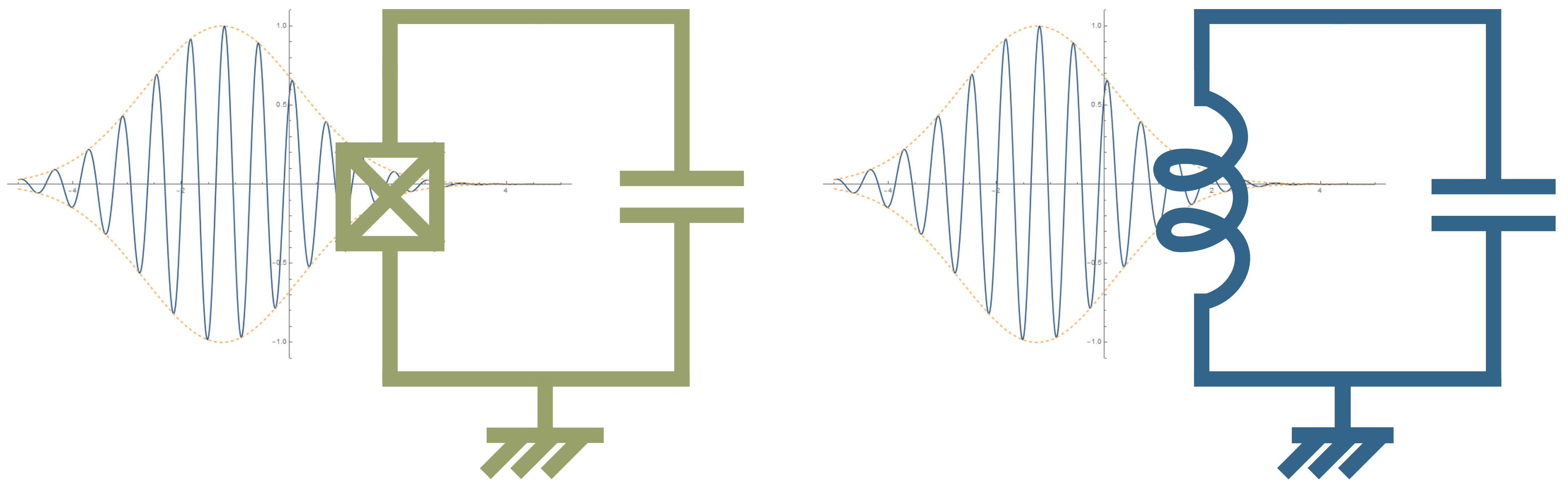
Due to the coupling between the qubit and the resonator, the resonator frequency shifts based on the qubit state.

Objective: Find the qubit frequency (Roughly)



How?

- Sweep a the frequency sent to the qubit.
- Measure the resonator response.
- A peak shift indicate qubit transition.



Rabi Measurement

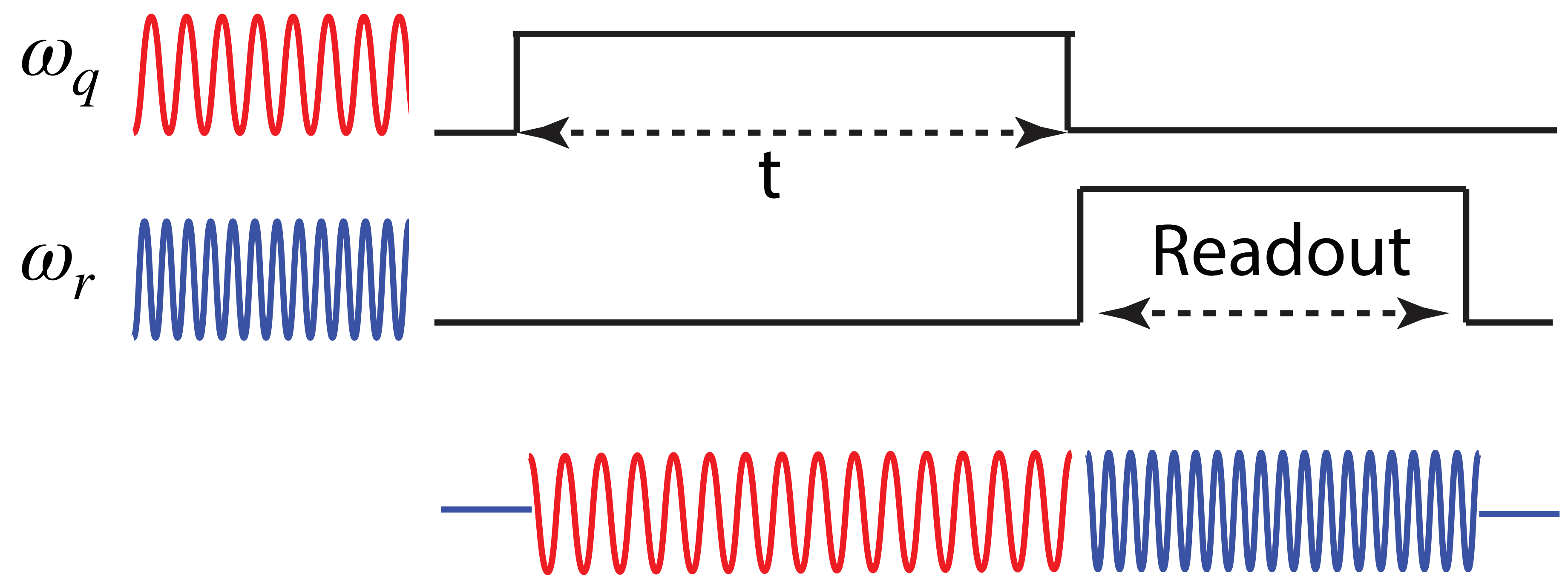
Rabi flopping is the main signature of a controllable qubit.

How?

Sweep the pulse frequency

+

Sweep the pulse length/amp



Objectives: Narrow down the qubit frequency.

Fine the pulse parameters for the X gate.

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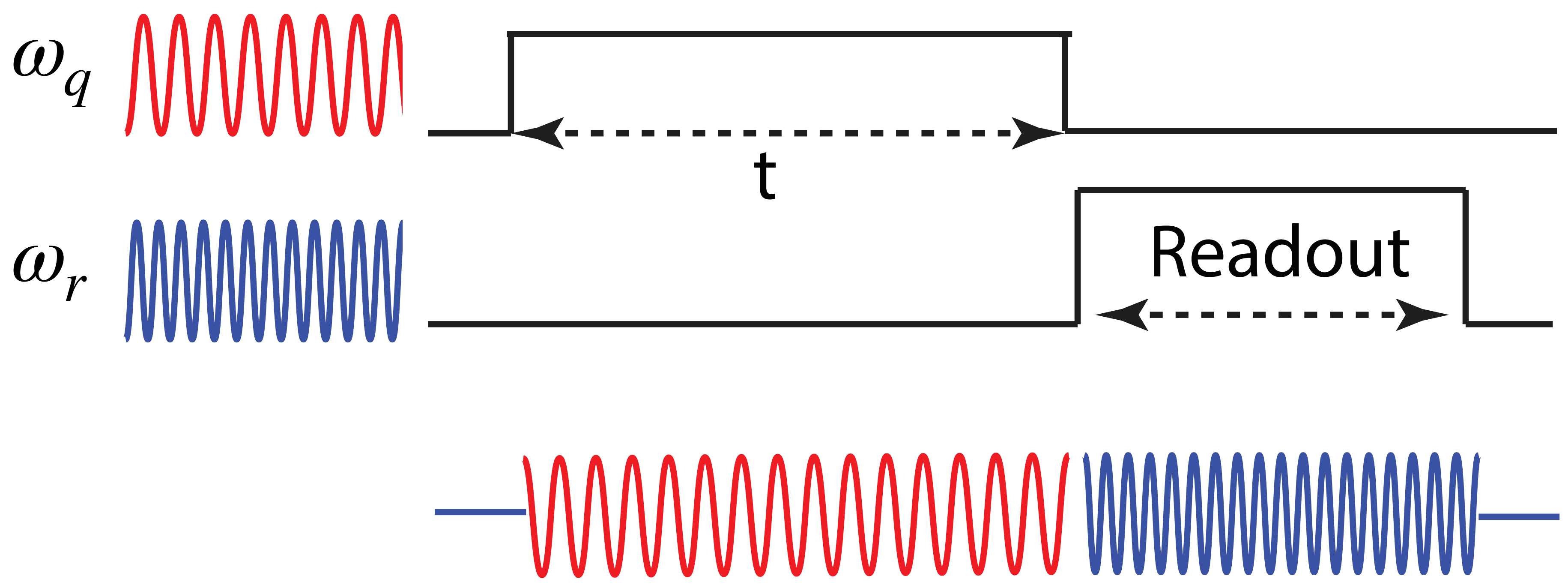

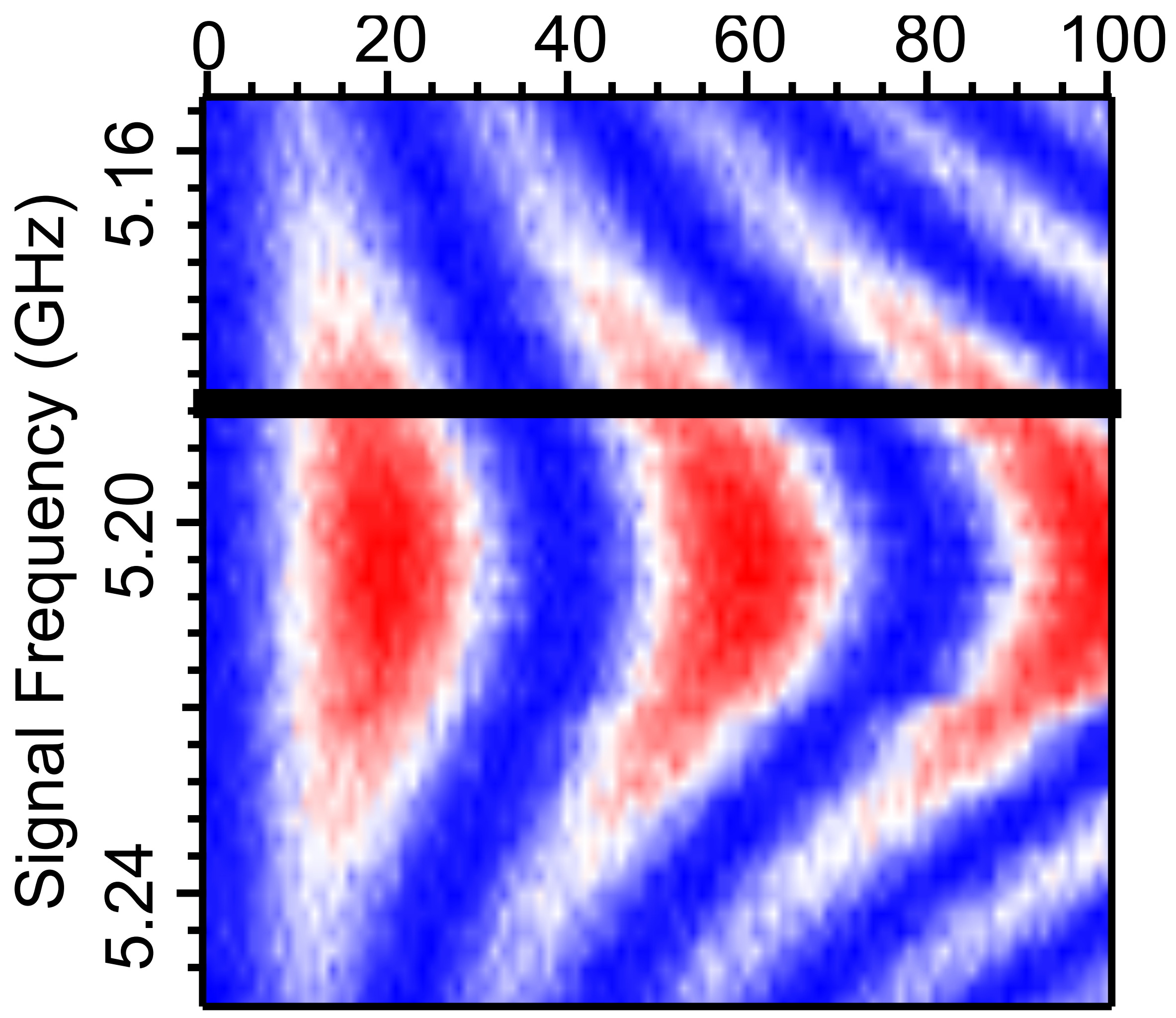

Naghiloo, M. (2019)

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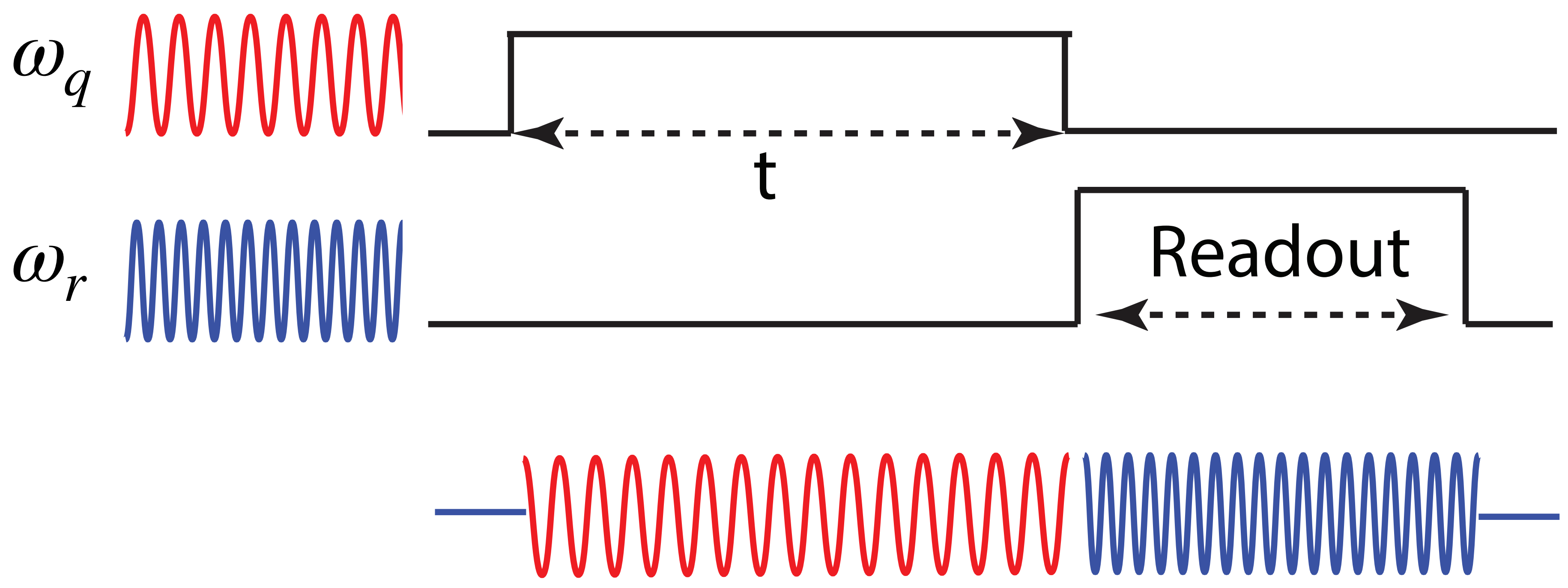

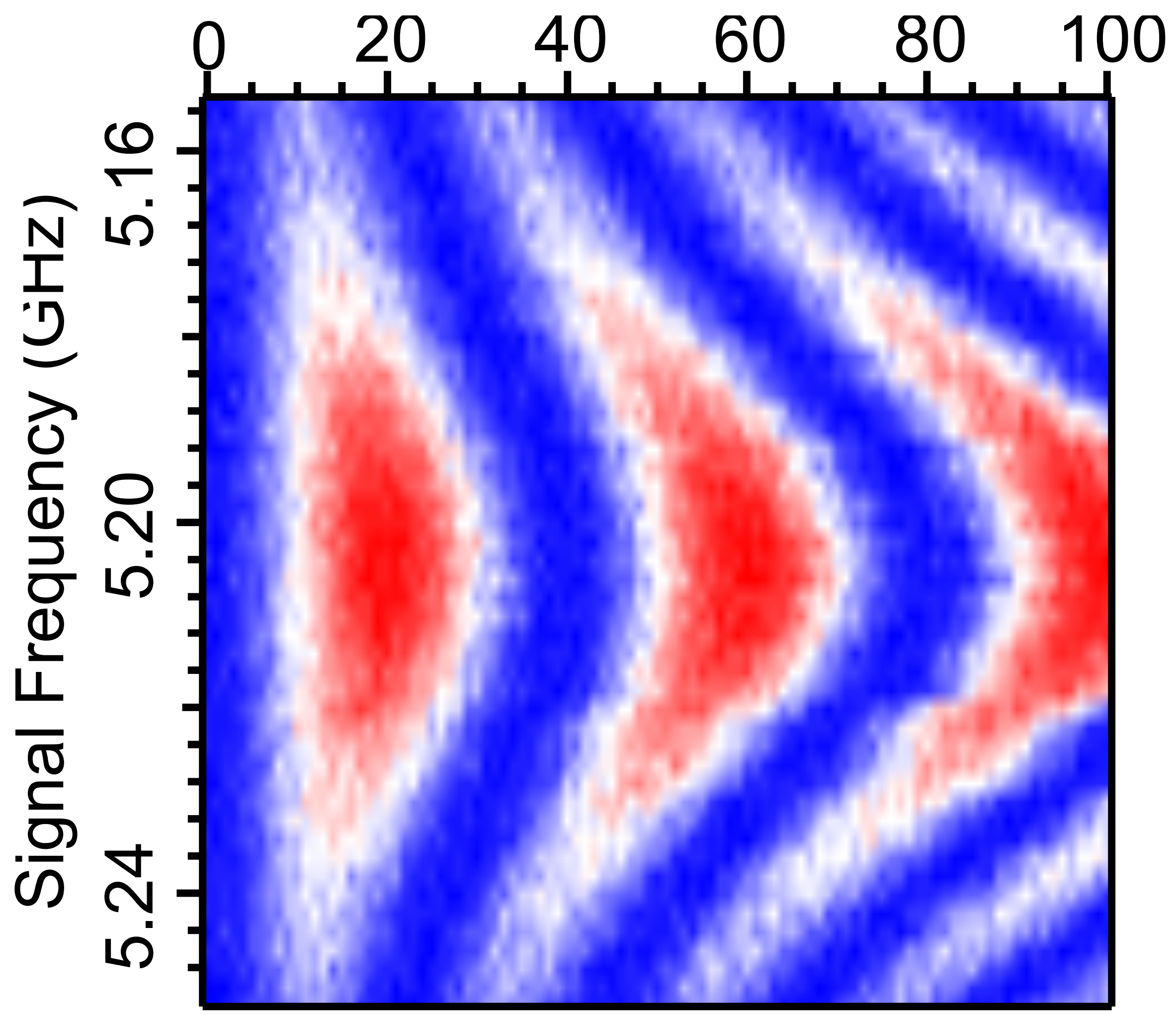

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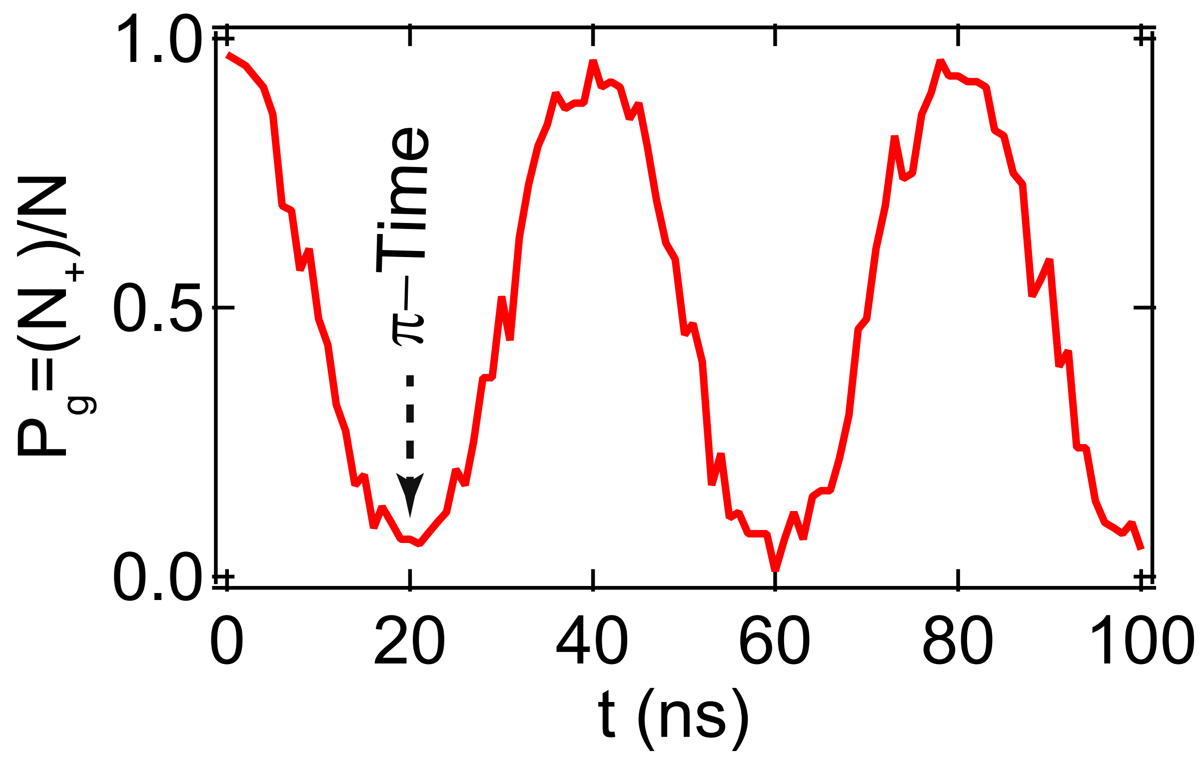

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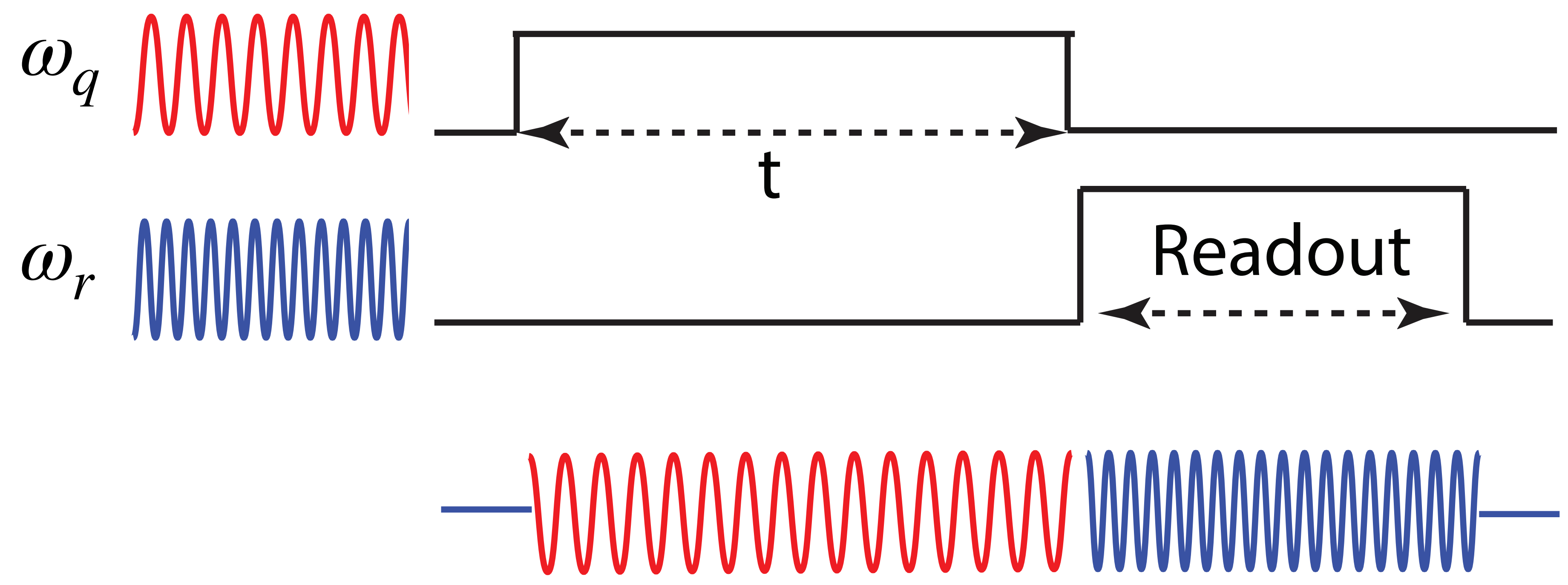

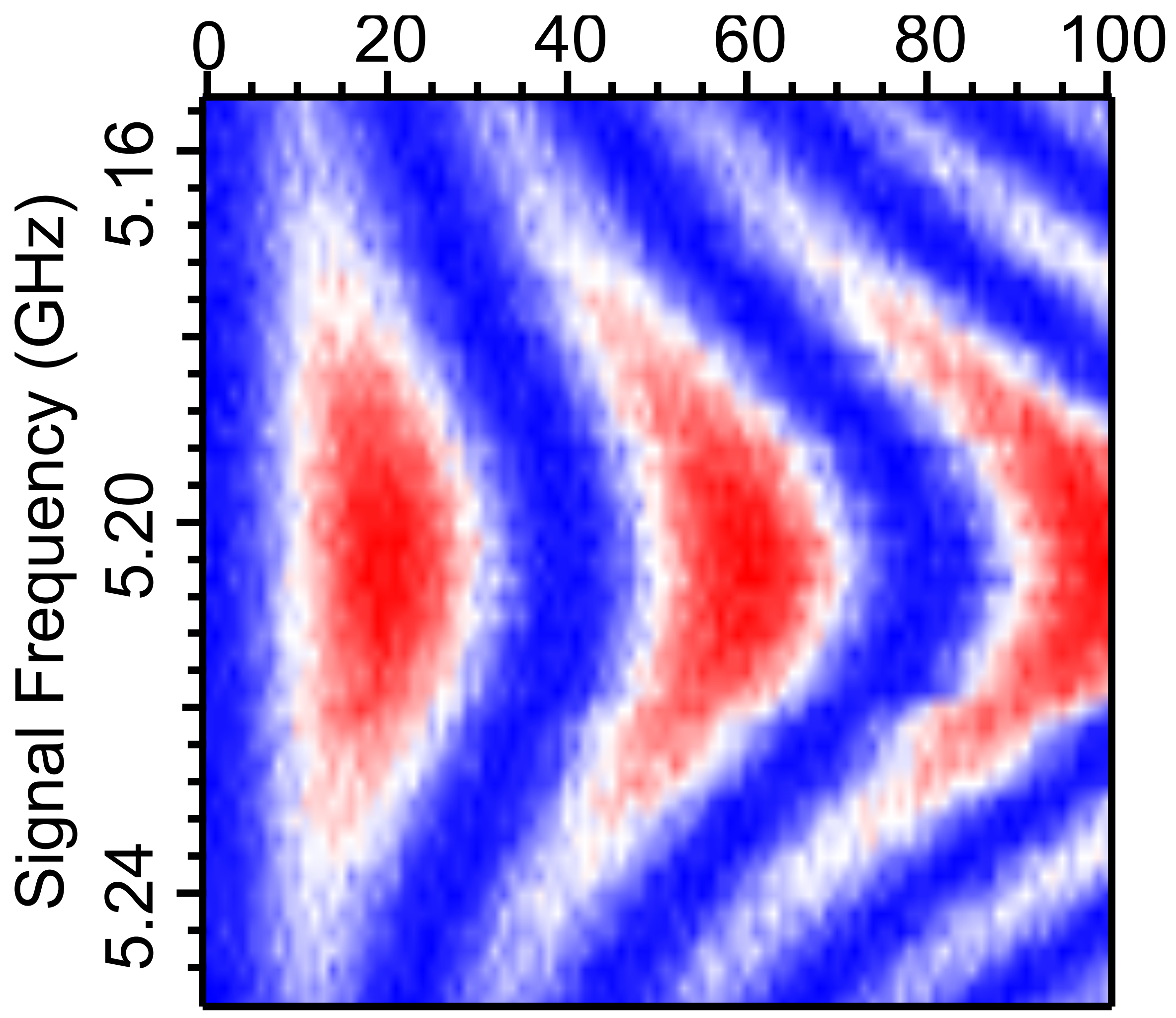

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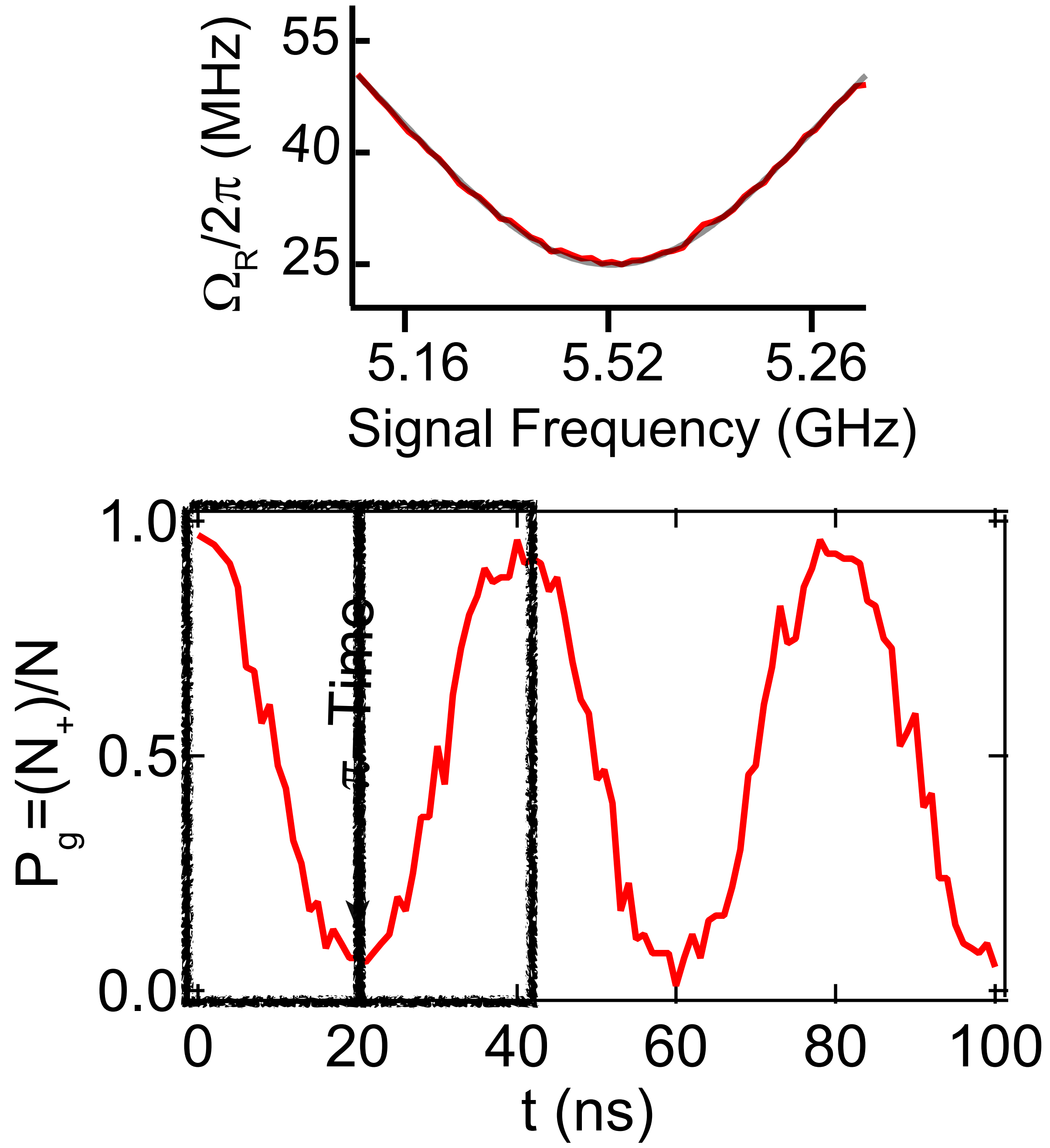
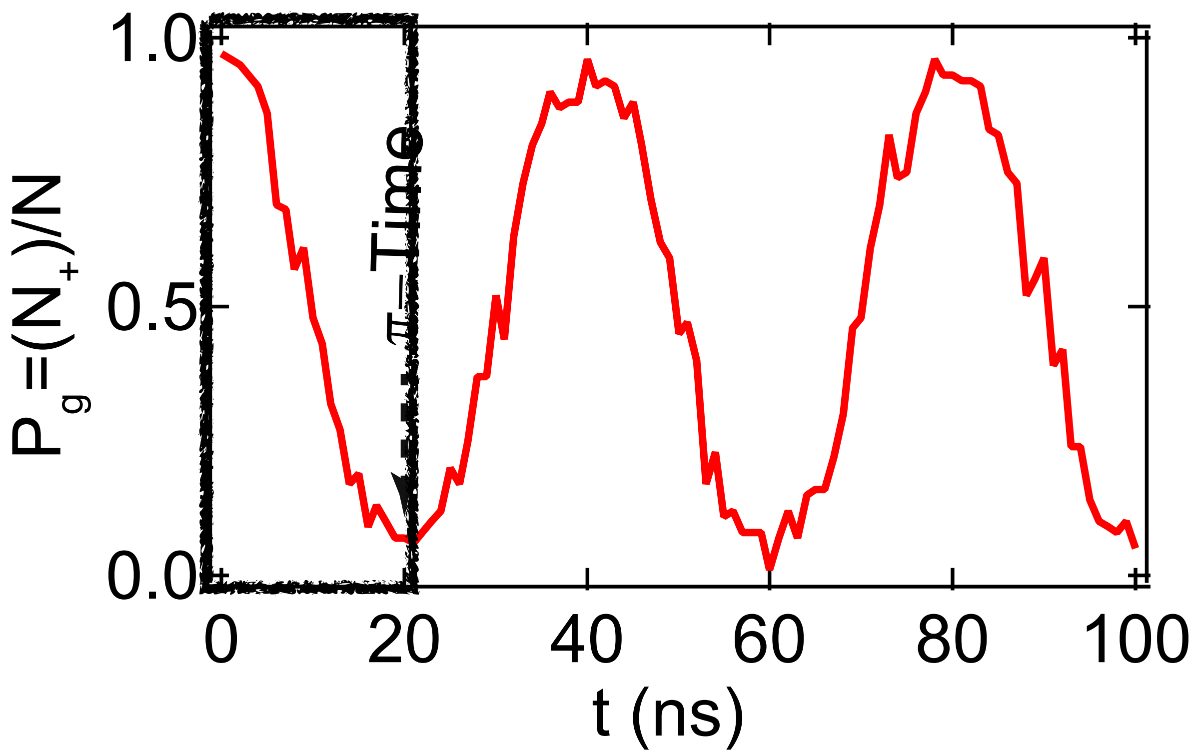
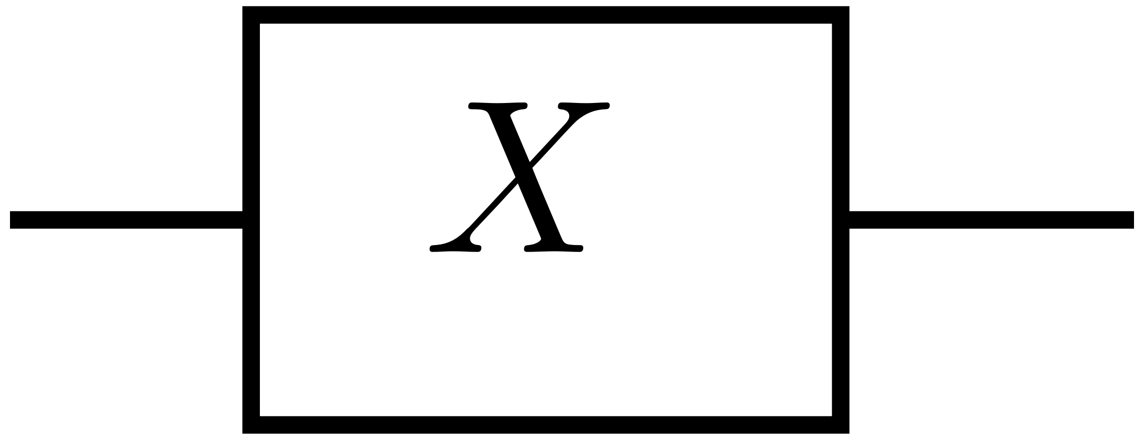


Qubit Calibration





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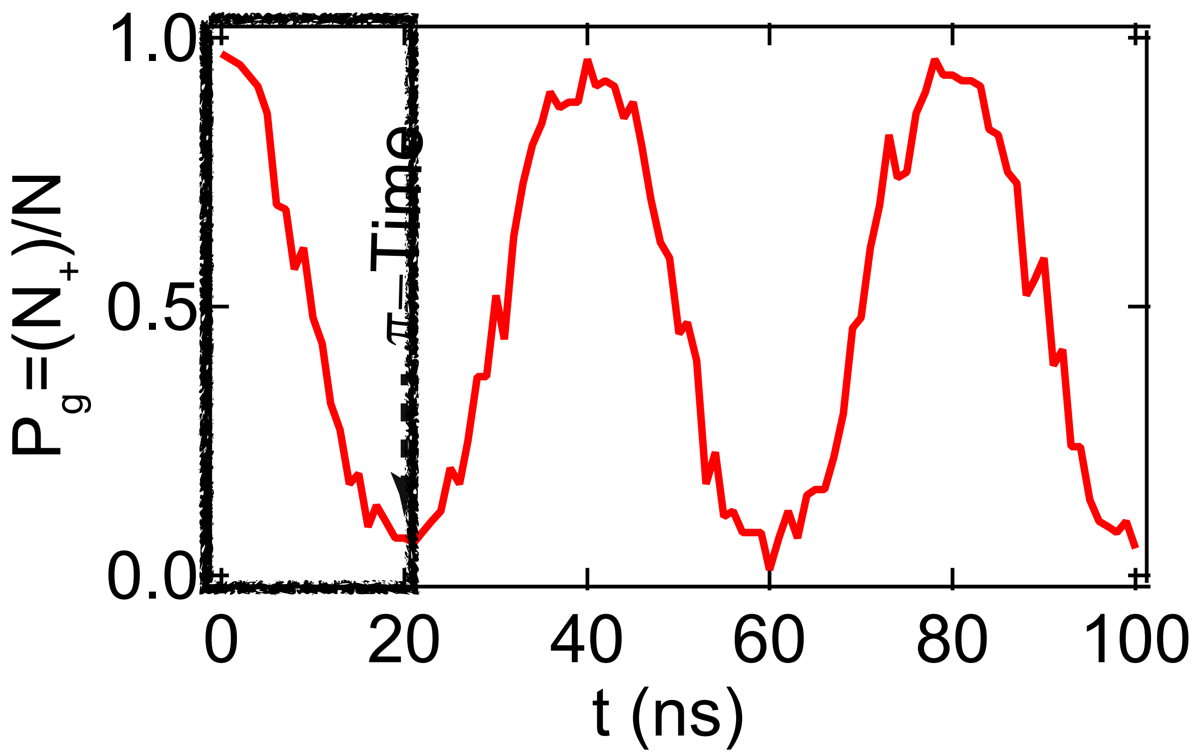

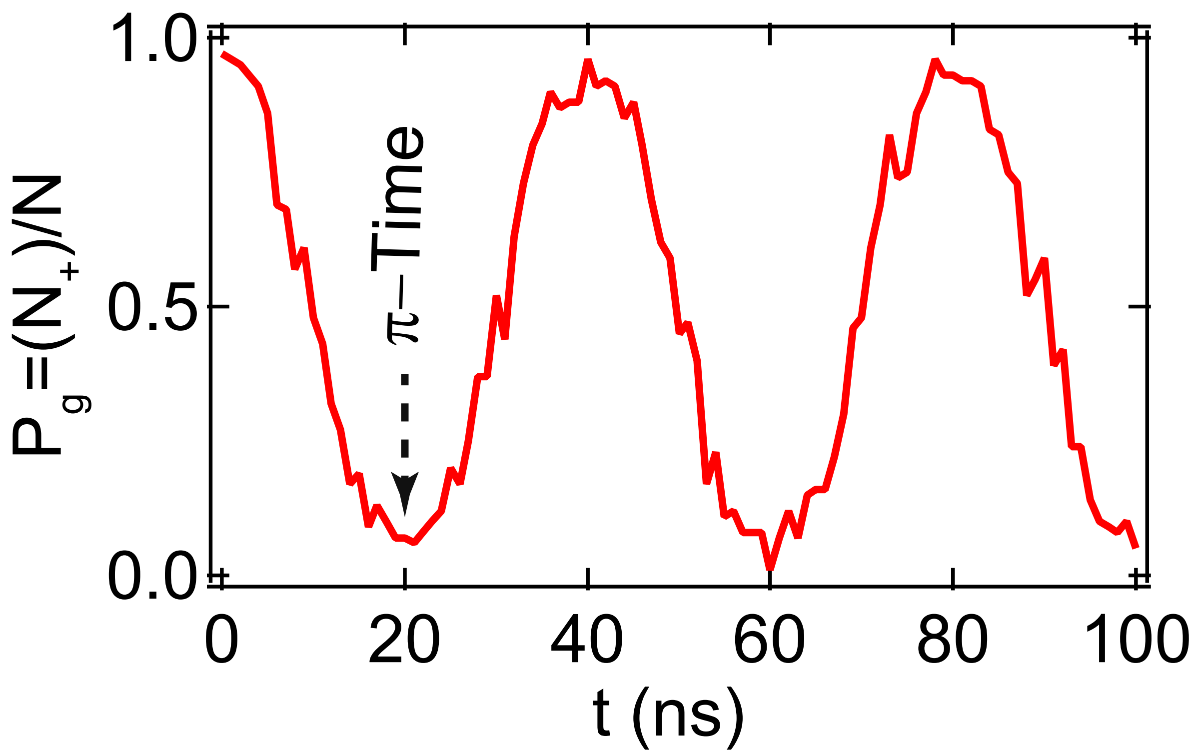

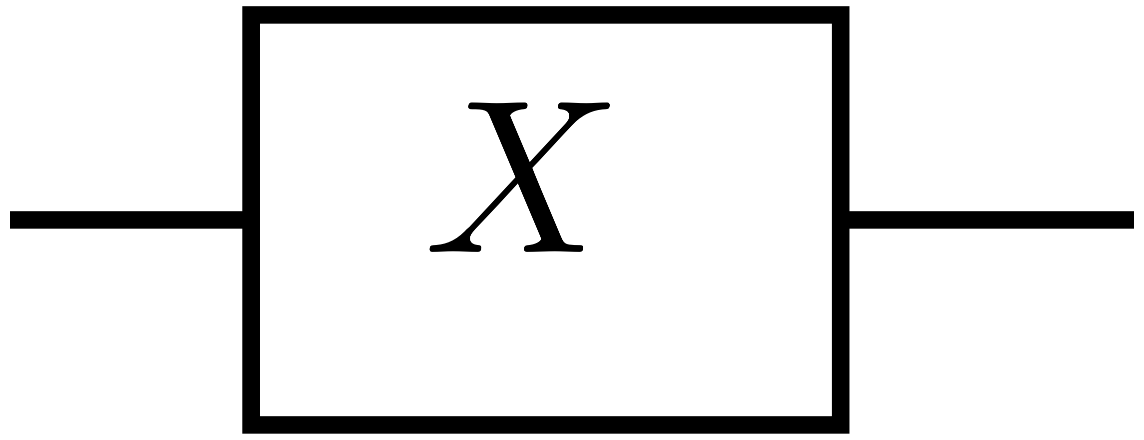

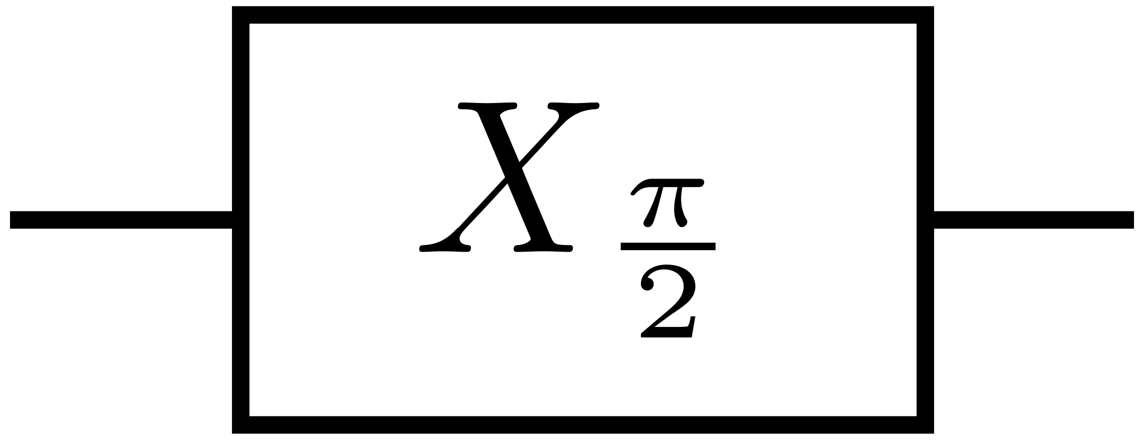

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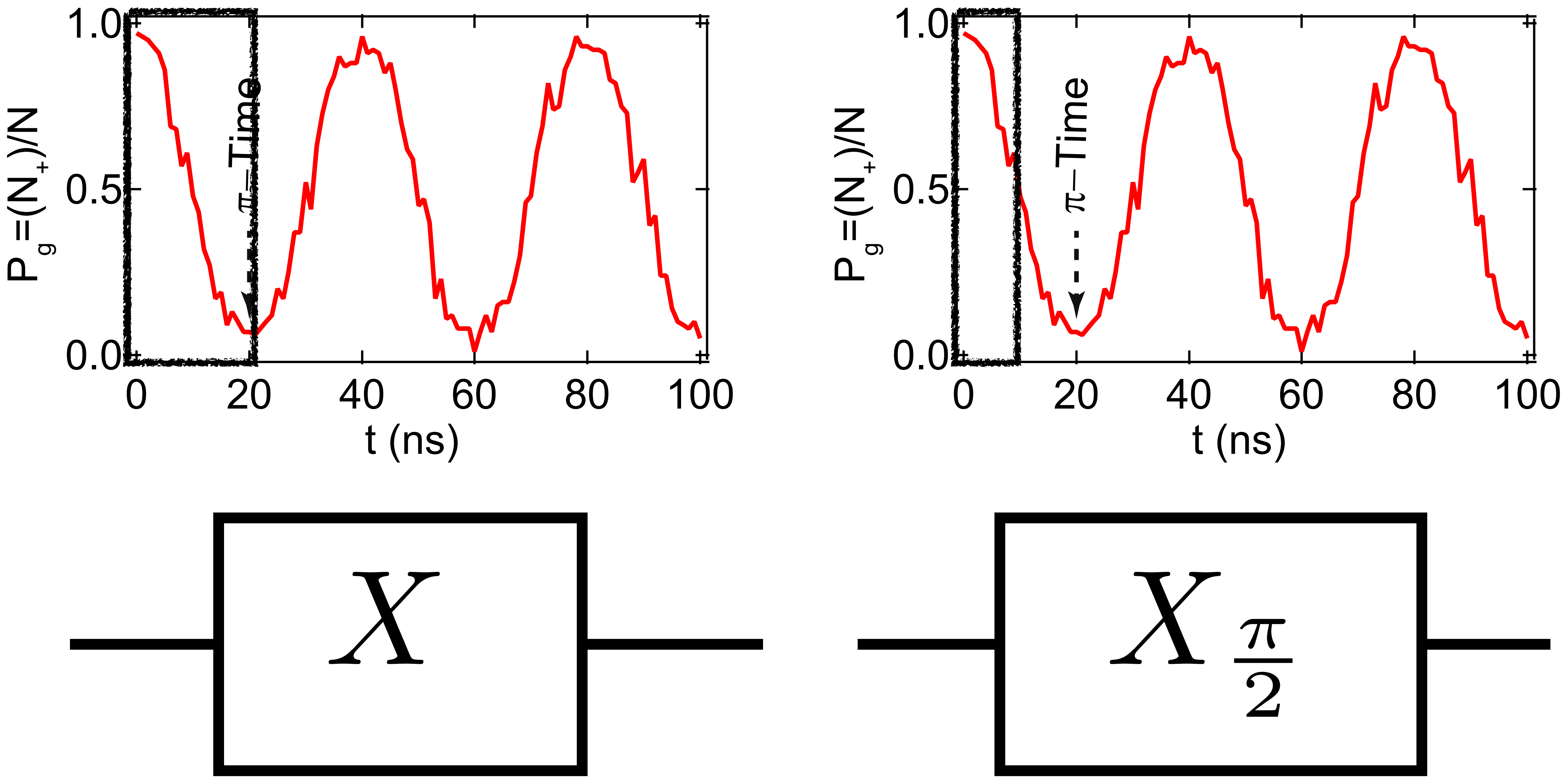

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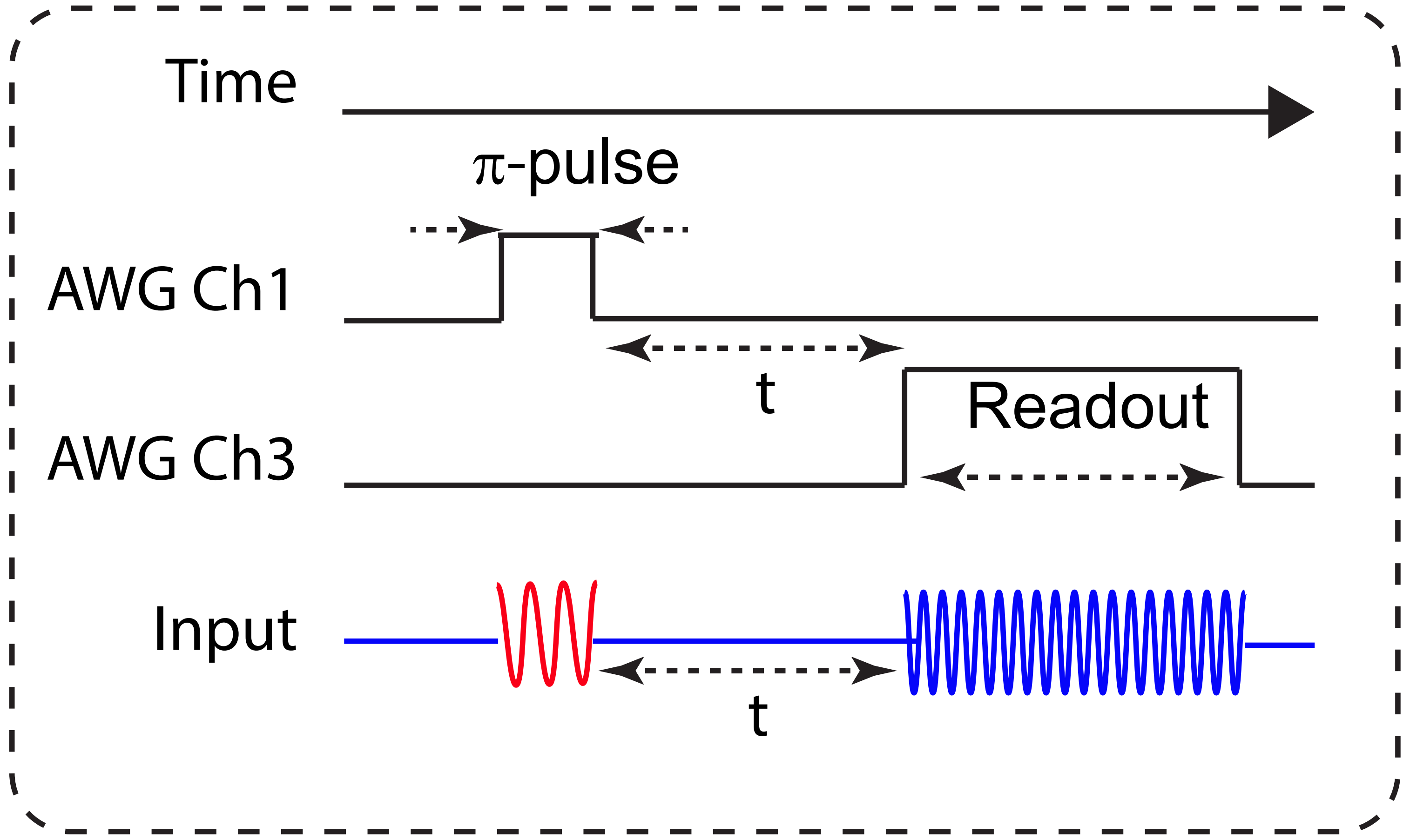
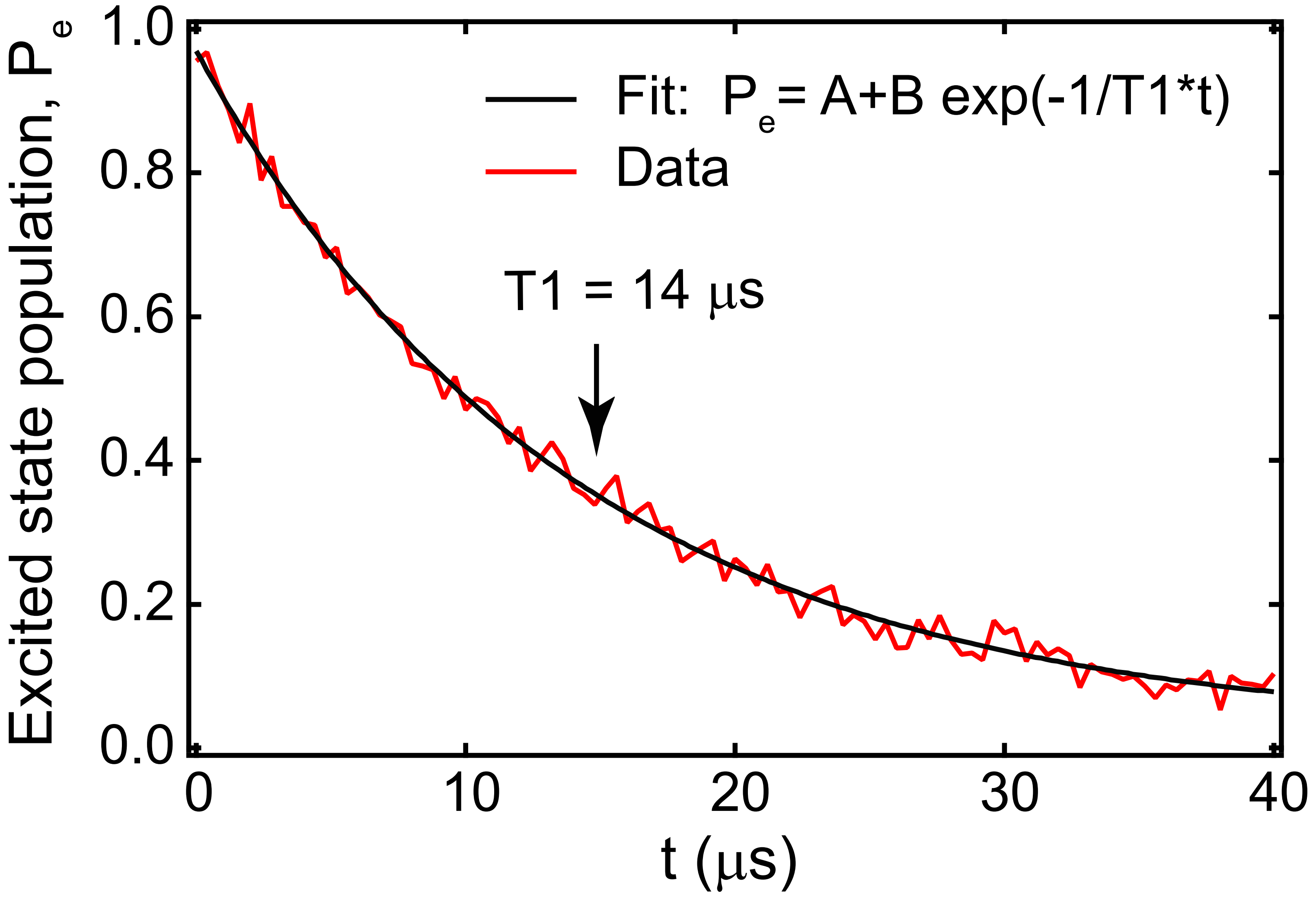
What can we do with these gate?

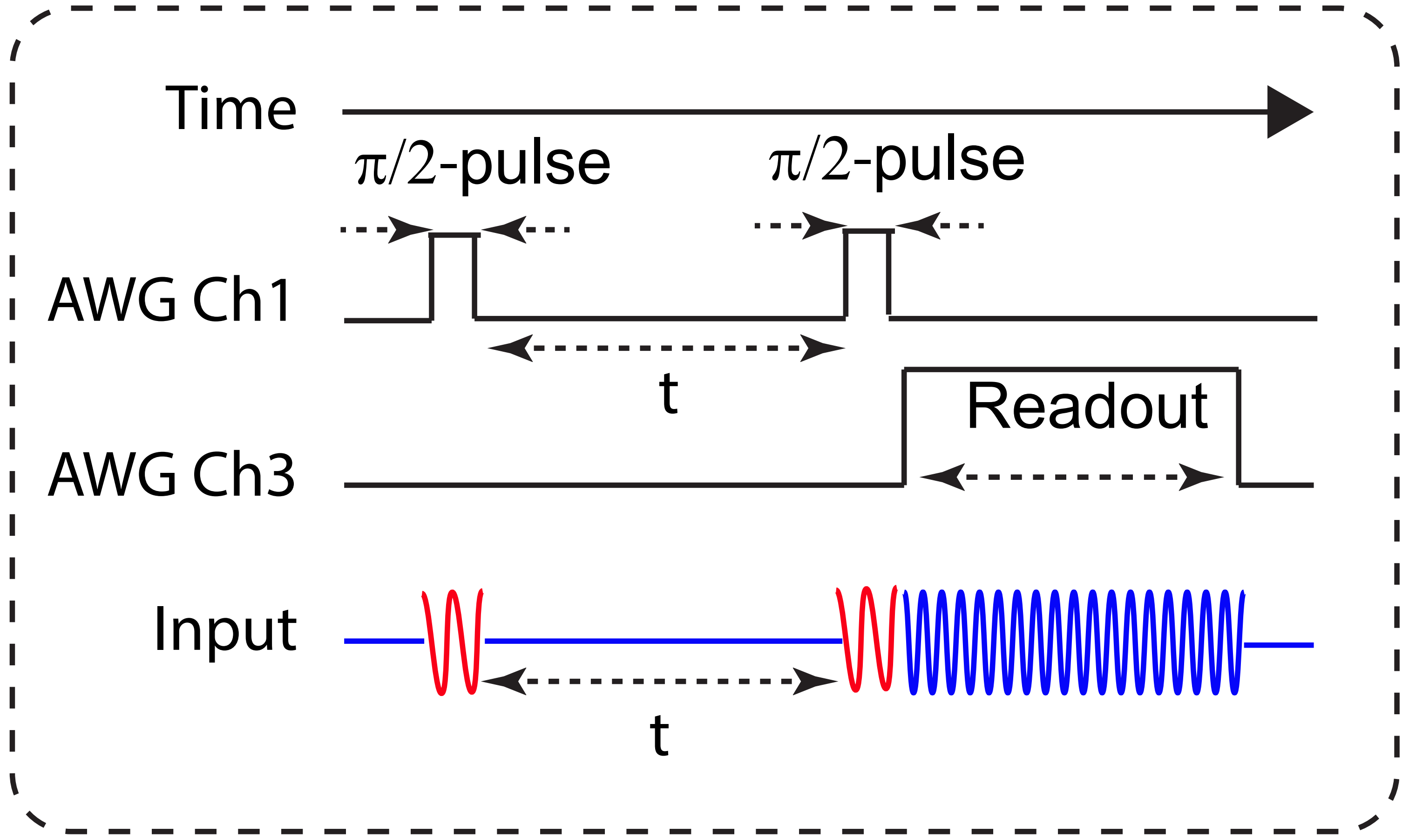
Qubit Characterization

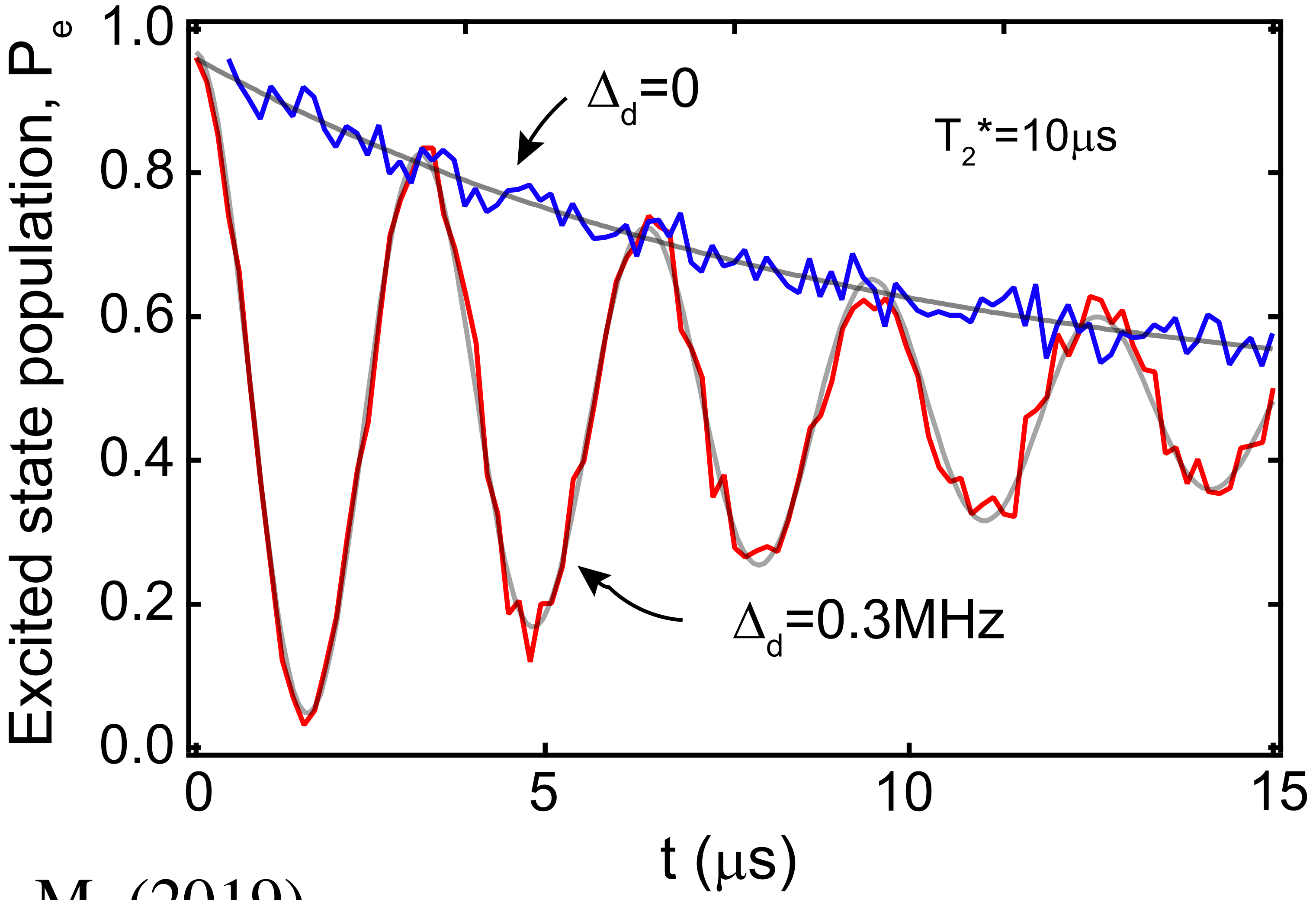
T1: Relaxation Time





T2*: Dephasing Time





Naghiloo, M. (2019)

Simulation Verifications

Simulation Verifications

QR for Notebook

Valuable References

Naghiloo, M. (2019). *Introduction to experimental quantum measurement with superconducting qubits*. arXiv. https://arxiv.org/abs/1904.09291

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