Robust Characterization of Gates

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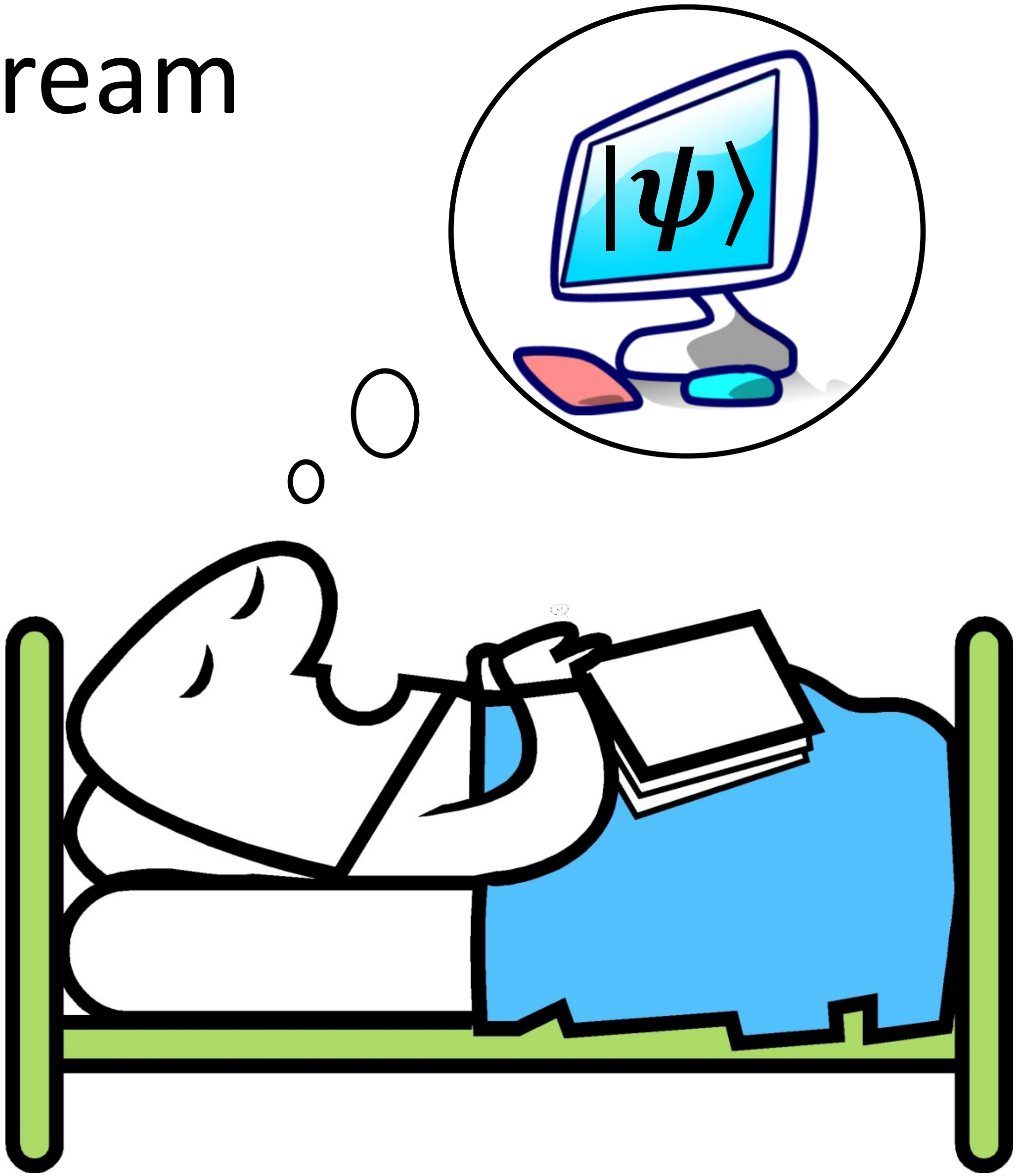
Joint Center for Quantum Information and Computer Science

University of Maryland

The Dream



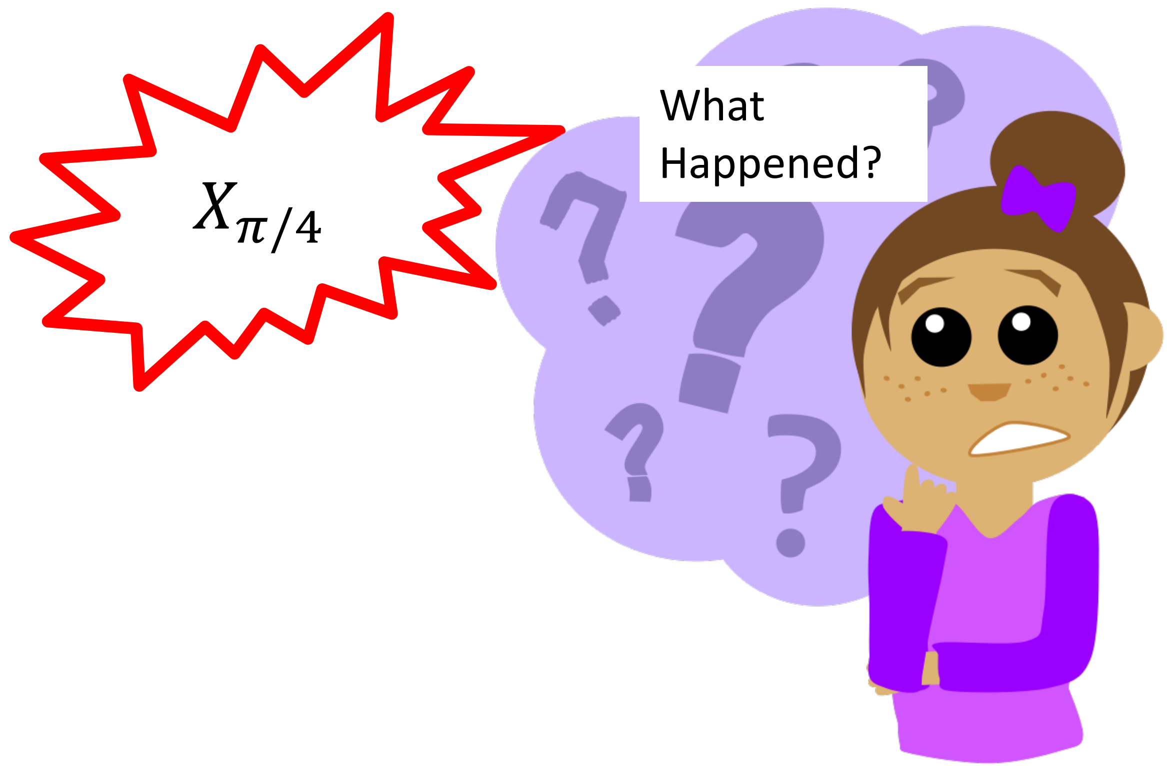
The Reality

$$\boxed{X_{\pi/4}}$$

The Reality

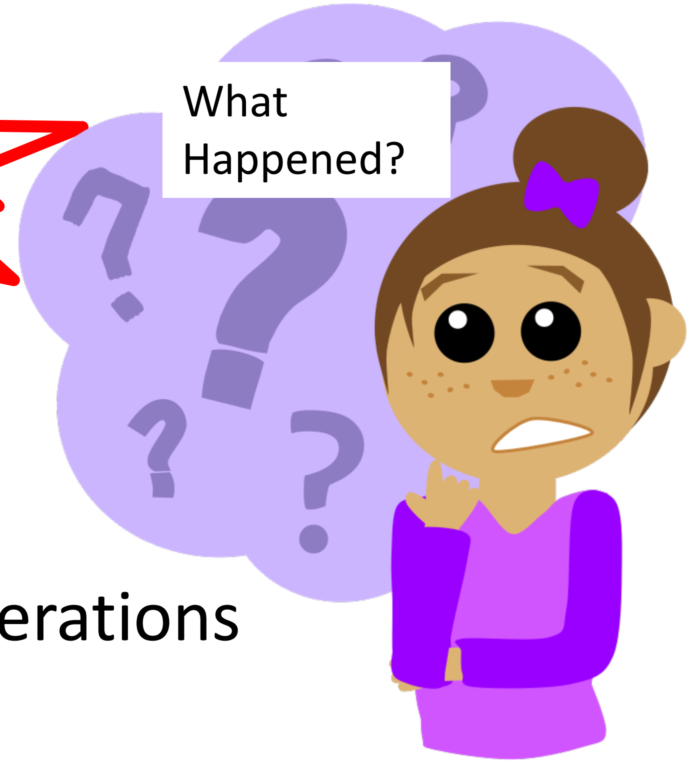
$X_{\pi/4}$

The Reality



The Reality

$X_{\pi/4}$



Standard Tomography:

- Inaccurate
- Results not valid quantum operations

The Solution

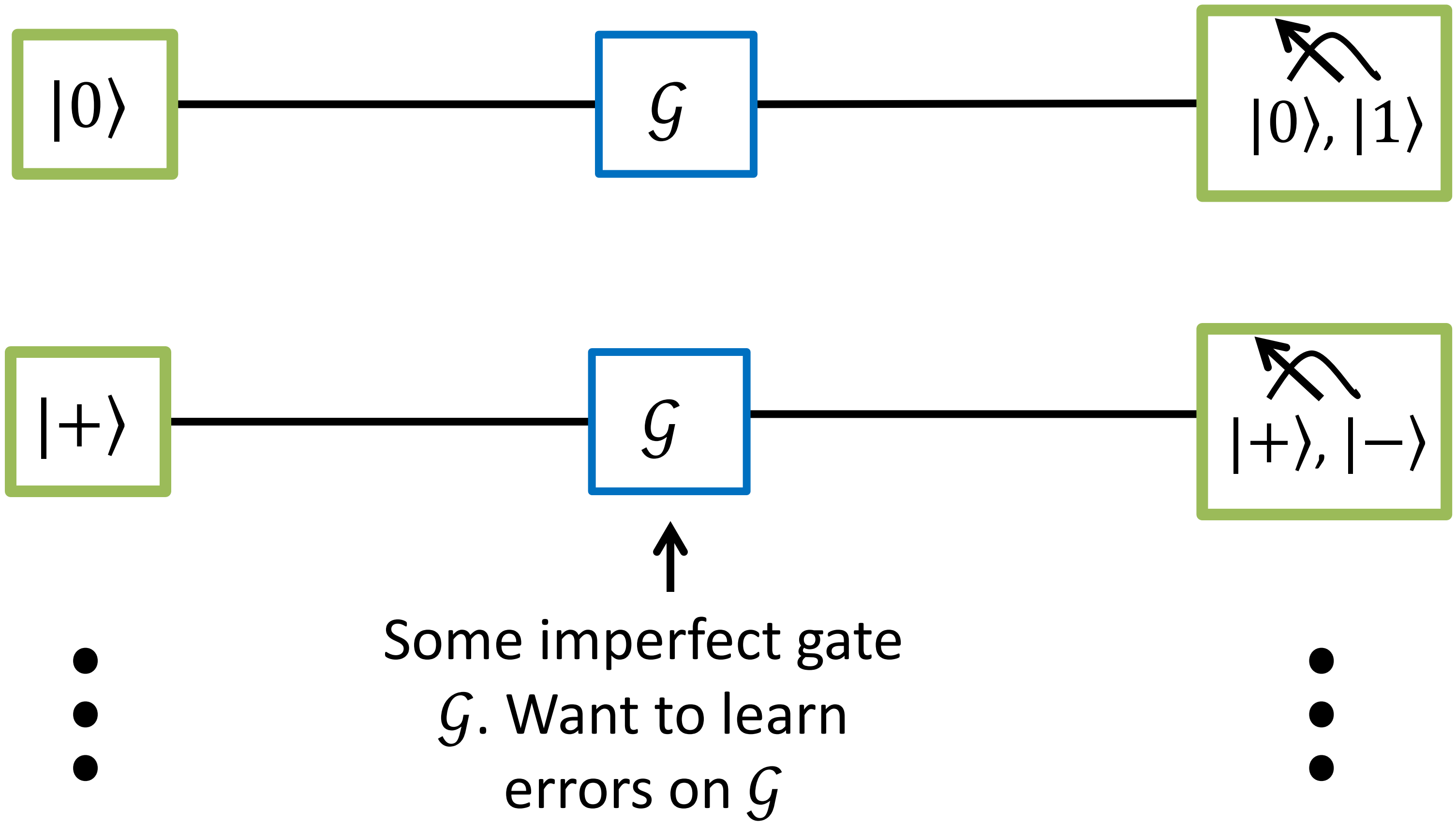
Robust Tomography:

$$\boxed{Dephase} - \boxed{X_{\pi/4.001}} - \boxed{Amp.D}$$

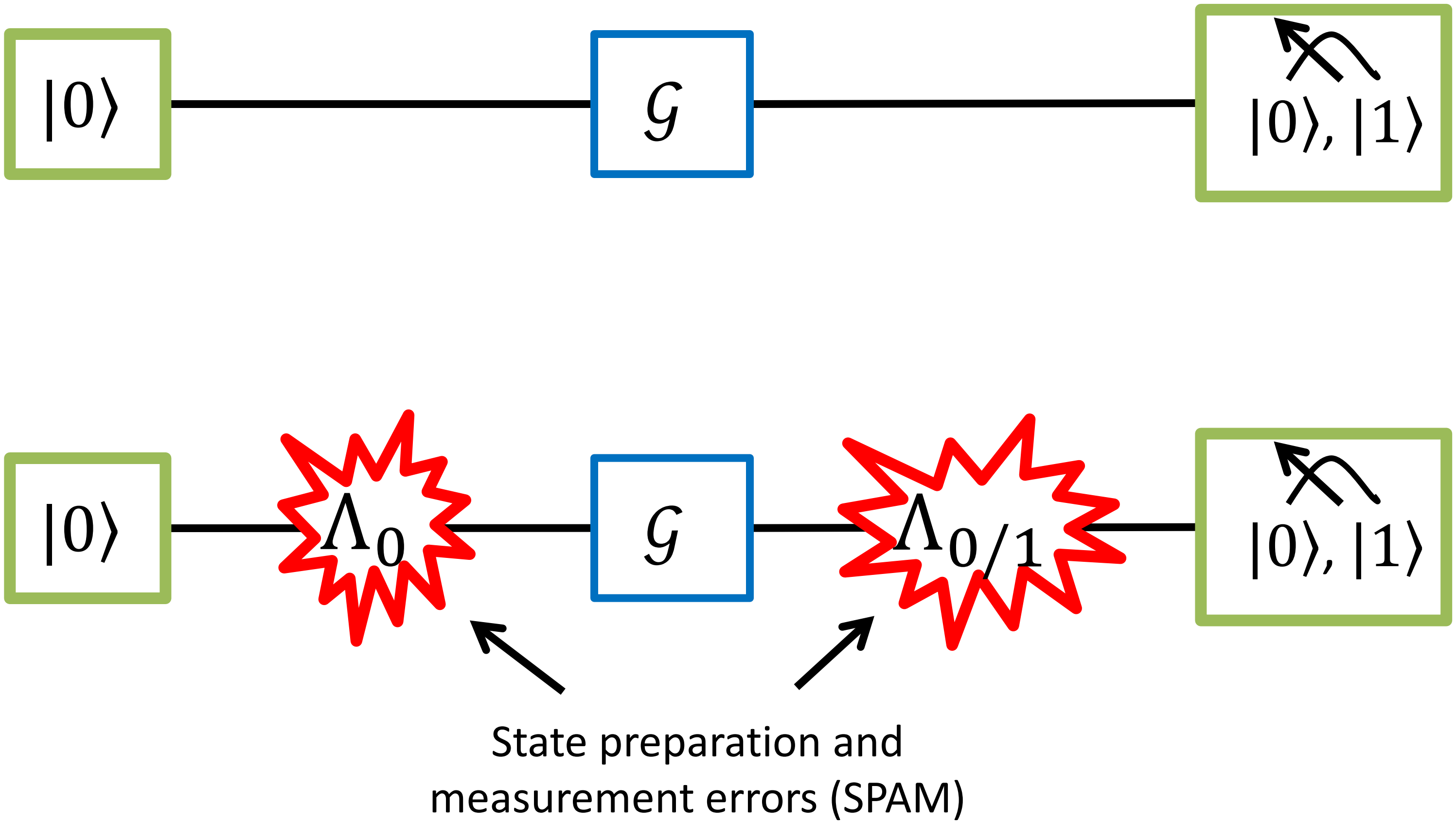
Outline

1. Why Standard Tomography Fails
2. Methods for Robust Tomography

Problem with Standard Process Tomography [Chuang & Nielsen '97]



Problem with Standard Process Tomography



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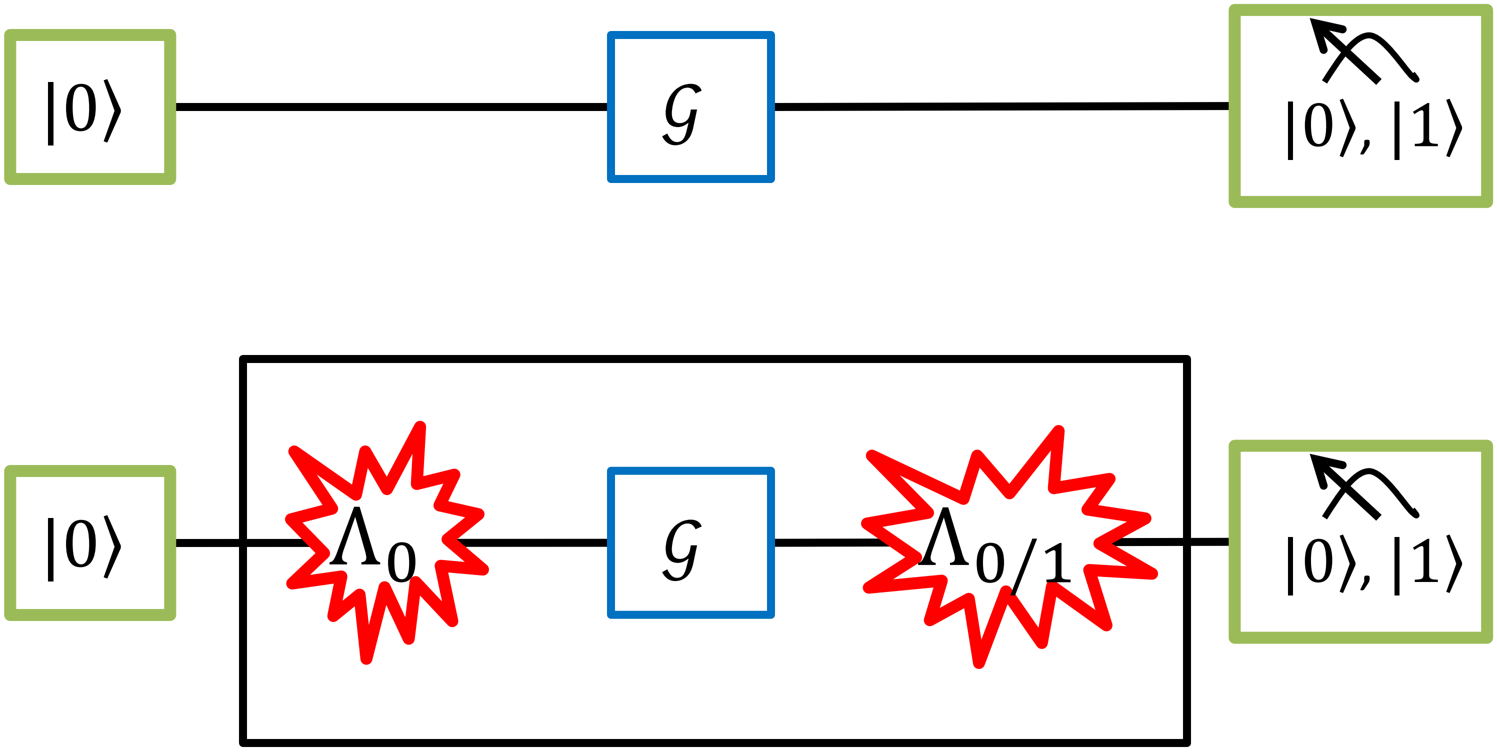

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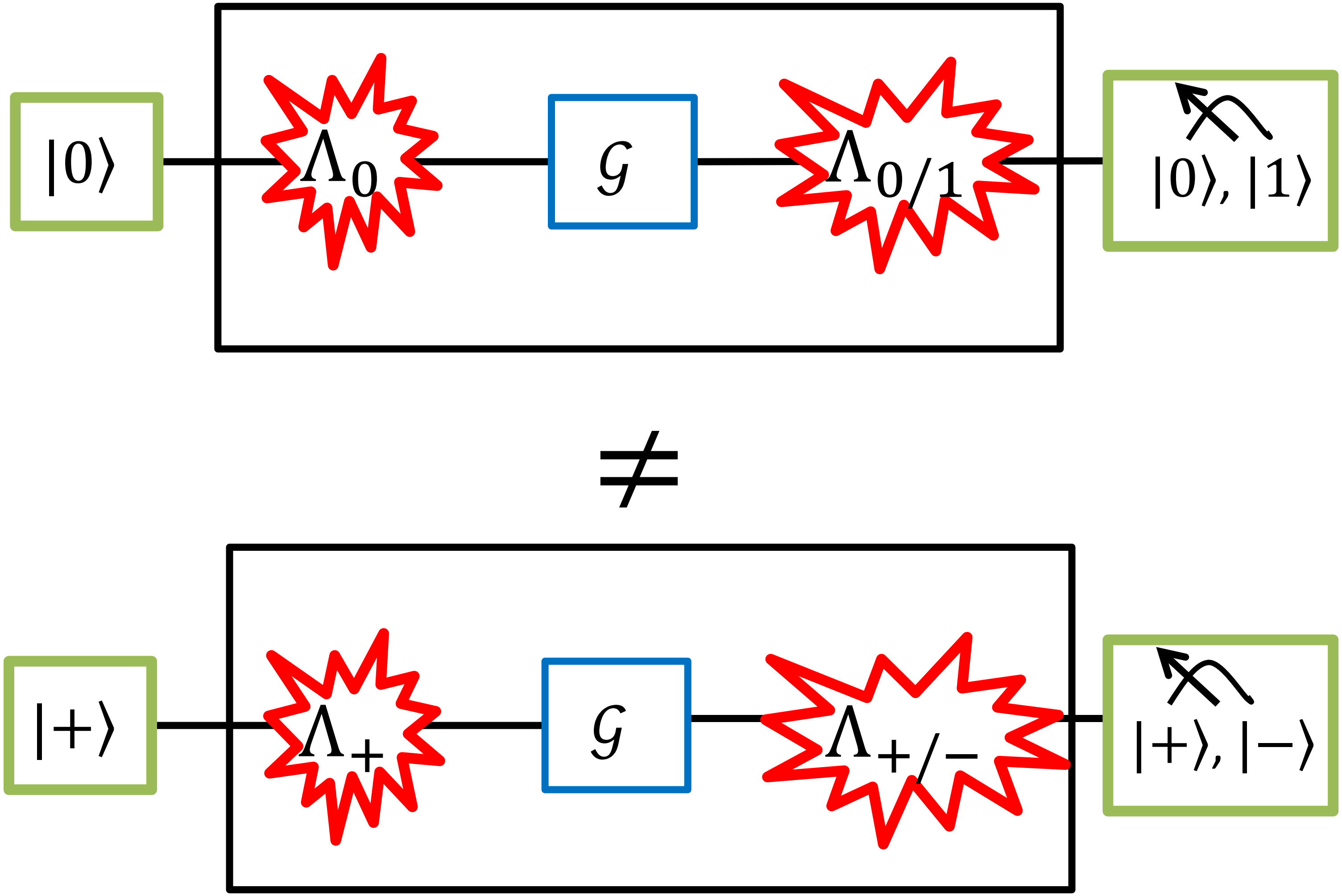
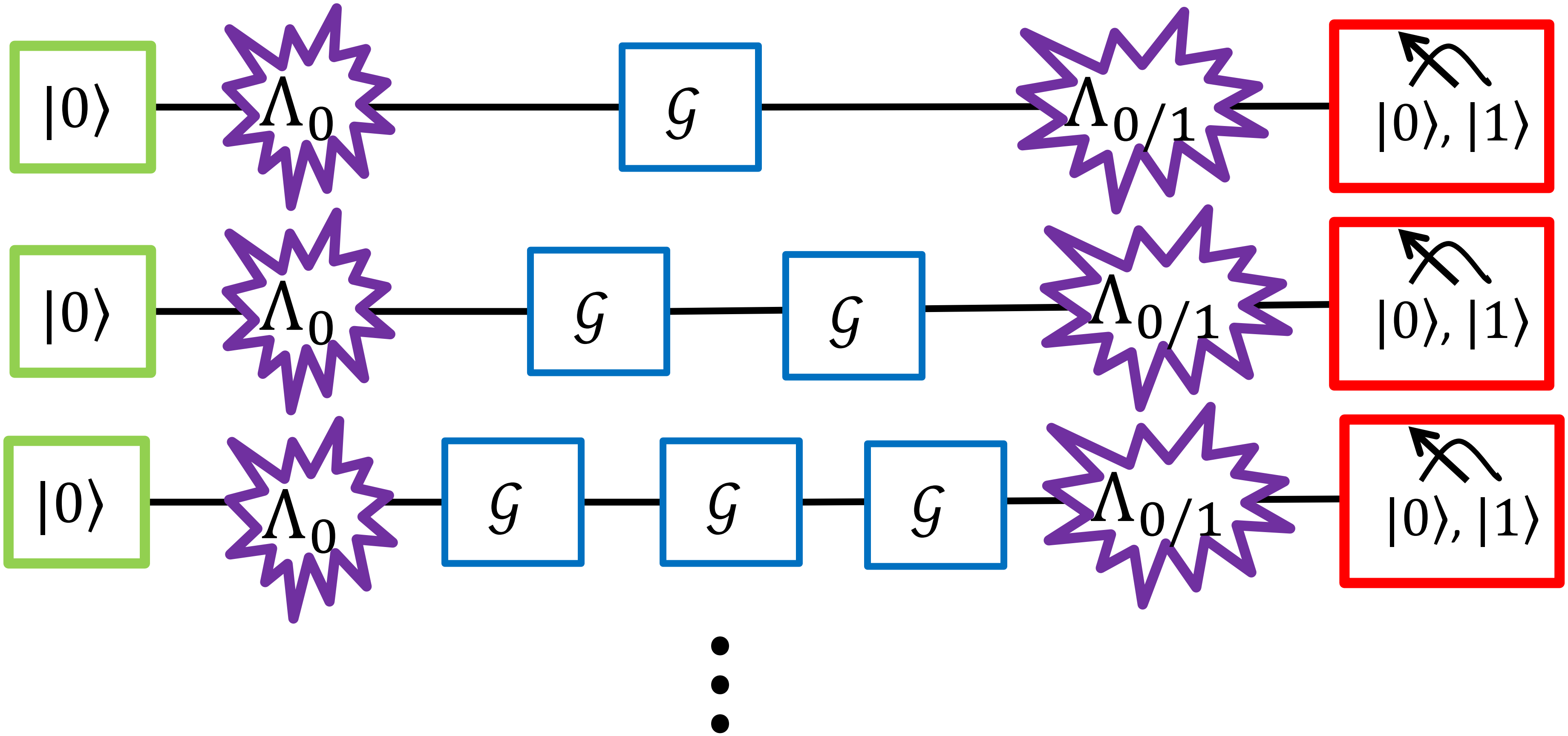


Methods that are Robust to SPAM

Two Approaches:

1. Repeated Application
2. Learn Everything at Once

Repeated Application



Any change outcome is due only to $\mathcal{G}$, not SPAM

Methods that are Robust to SPAM

Two Approaches:

1. Repeated Application
2. Learn Everything at Once

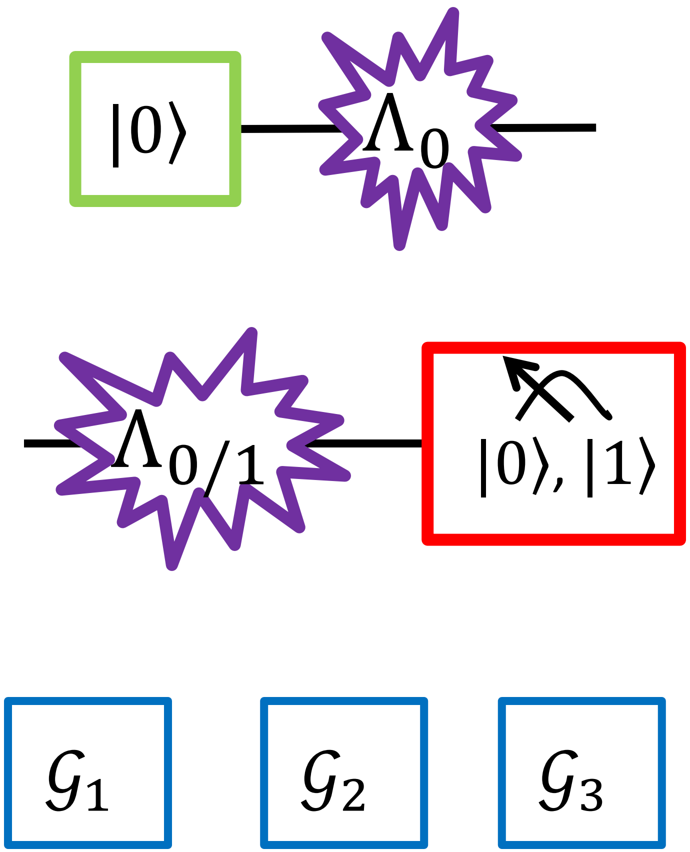
Learn Everything at Once

Actions that can be performed

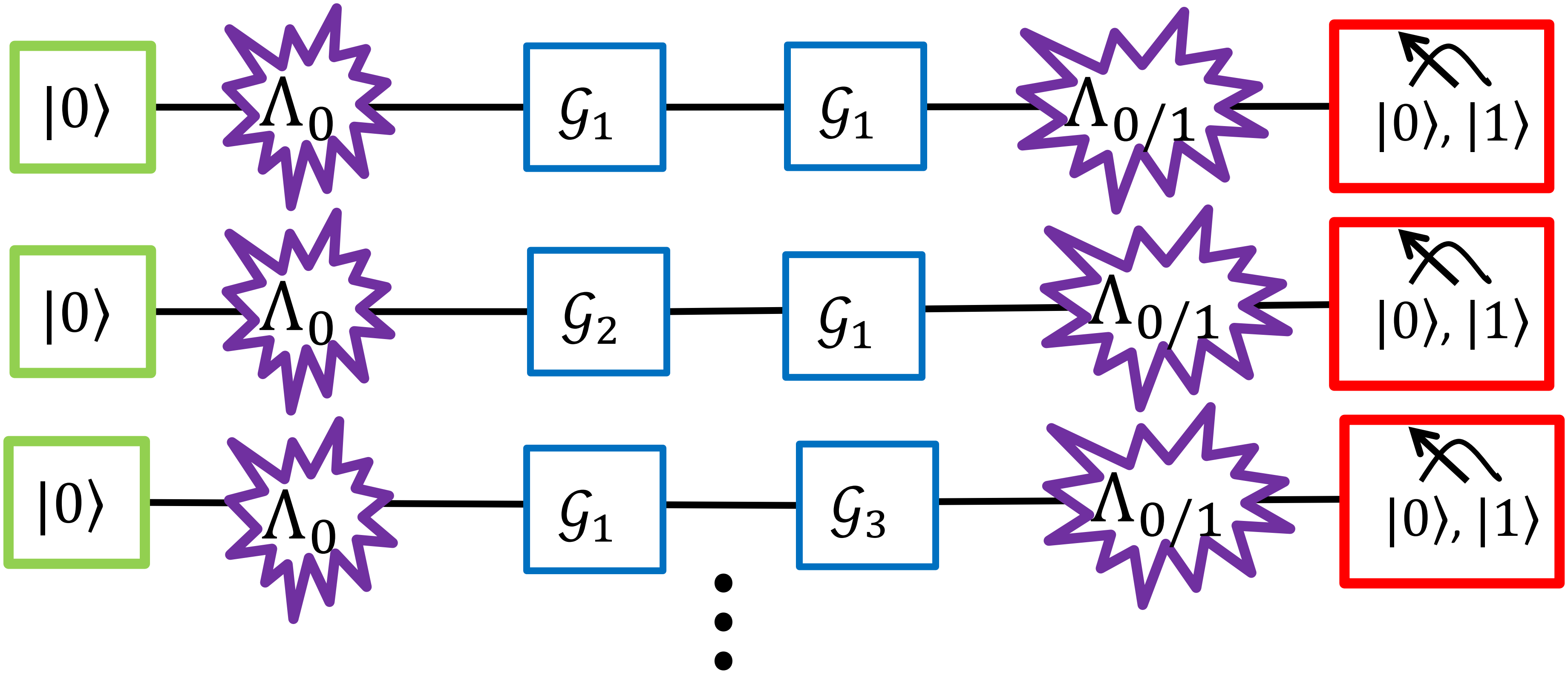
State Prep:

Measurement:

Noisy Gates:



Learn Everything at Once



Get a ton of data, then solve for everything at once, including SPAM rather than just one gate at a time

Methods that are Robust to SPAM

Two Approaches:

1. Repeated Application
   a) Randomized Benchmarking
   [Emerson et al ‘05, Knill et al ‘08, Magesan et al‘12, Kimmel, da Silva et al ’14, Wallman et al ‘15, etc]
   a) Robust Phase Estimation [Kimmel, Low, Yoder ‘15]
2. Learn Everything All At Once
   a) Gate Set Tomography
   [Stark ’12, Merkel et al ‘13, Blume-Kohout et al ’13 (Sandia National Labs)]

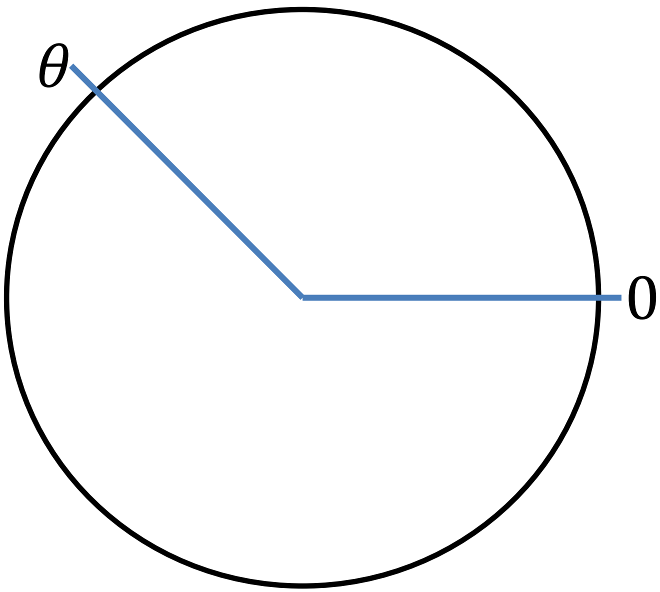
Comparing Methods

	Randomized Benchmarking	Robust Phase Estimation	Gate Set Tomography
Efficiency	Polynomial in # qubits	Heisenberg scaling	Exponential in # of qubits
Size of system to characterize	Multiple qubits	Single qubit	3 qubits max in practice
Type of Parameters Extracted	Course-grained	Specific, Experimentally relevant	Everything
Additional Resources	Clifford operations	None	None
Ease of use	Very easy to use and analyze	Easy to use and analyze	Easy to use b/c software, harder to analyze

Goals for the Future

- Targeted, experimentally relevant information efficiently, robustly.

Robust Phase Estimation

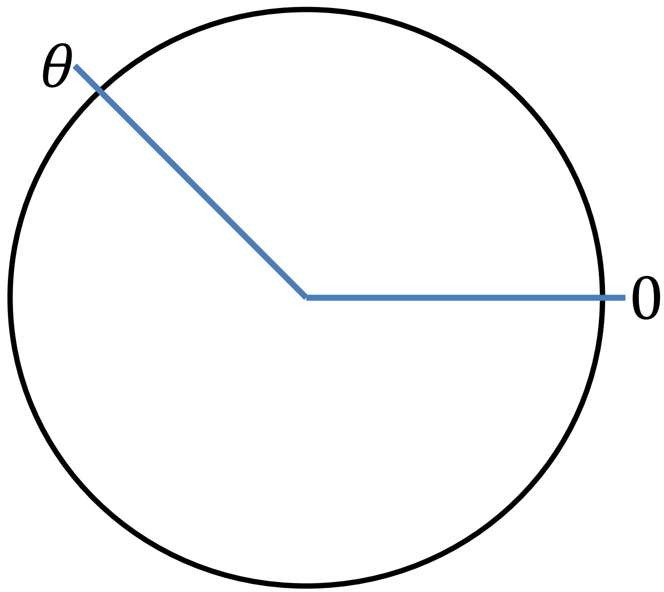


Can sample from 2 binomial random variables with probability of "heads"

$$\frac{1+\sin k\theta}{2}+\delta_{k1}, \qquad \frac{1+\cos k\theta}{2}+\delta_{k2}$$

For k in $\mathbb{Z}$, each in time k

Robust Phase Estimation



Can sample from 2 binomial random variables with probability of "heads"

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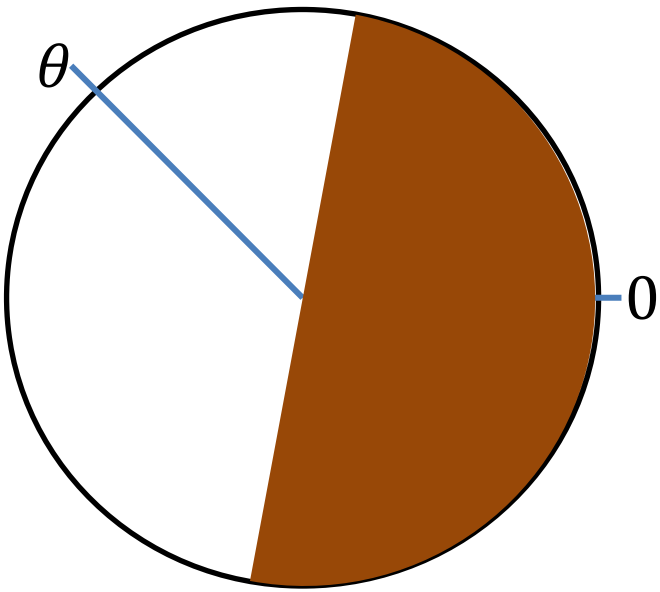
Using only $k = 1$ can't get an accurate estimate!

Robust Phase Estimation



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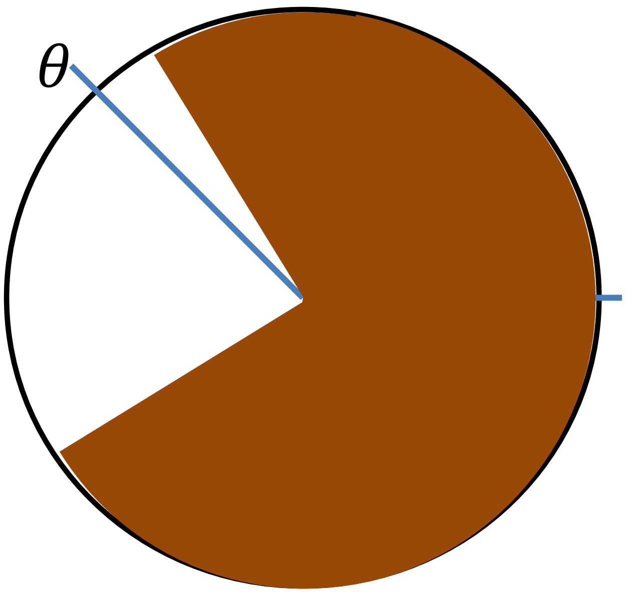

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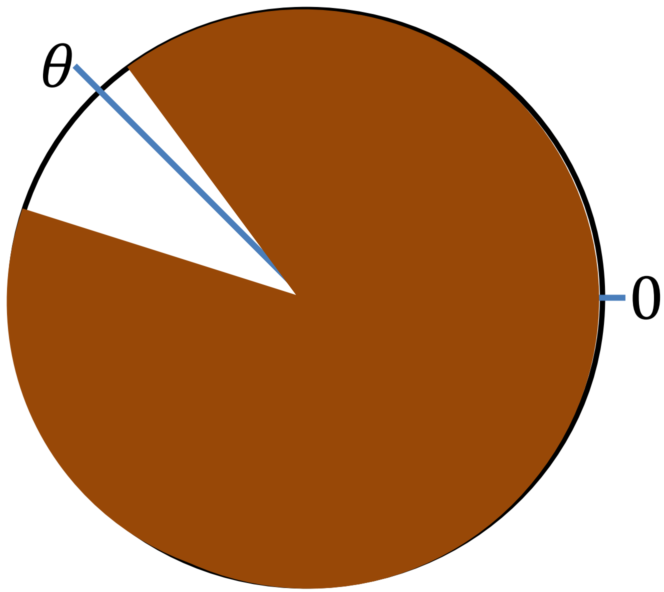

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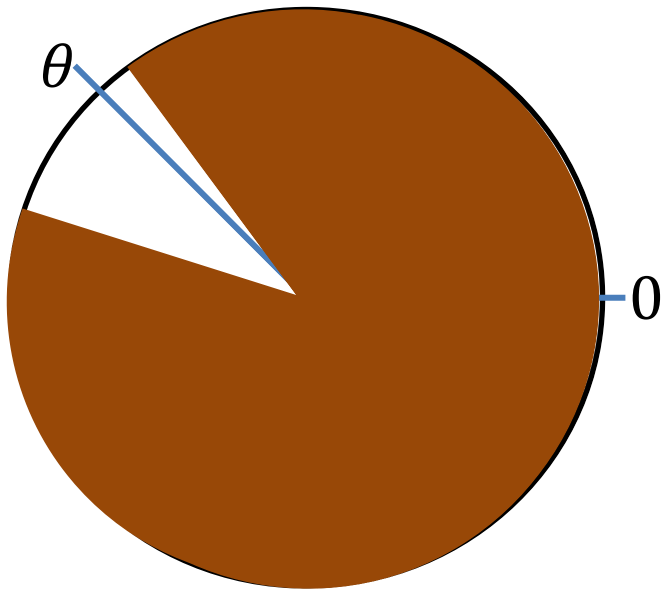
$k=1 \qquad k=2 \qquad k=4$

Can estimate θ with standard deviation $\sigma(\theta) \sim \frac{1}{T}$,

as long as $|\delta_k| < \frac{1}{\sqrt{8}} \approx .35$ for all k.

Robust Phase Estimation



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Can estimate θ with standard deviation $\sigma(\theta) \sim \frac{1}{T}$,
as long as $|\delta_k| < \frac{1}{\sqrt{8}} \approx .35$ for all k.
…but need upper bound on size of δ to know how many extra samples to take.