Robust, Universal-Single-Qubit-Gate-Set Calibration via Robust Phase Estimation

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JOINT CENTER FOR QUANTUM INFORMATION AND COMPUTER SCIENCE

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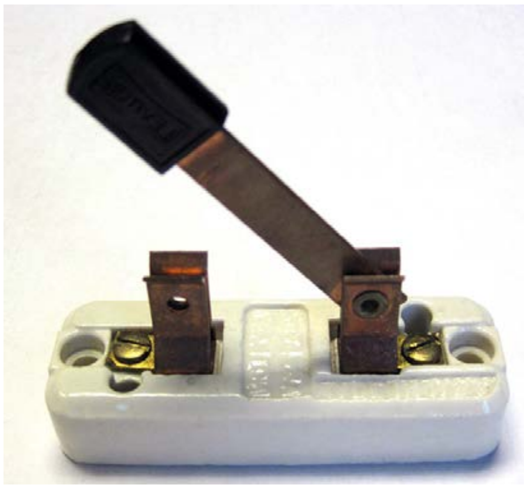
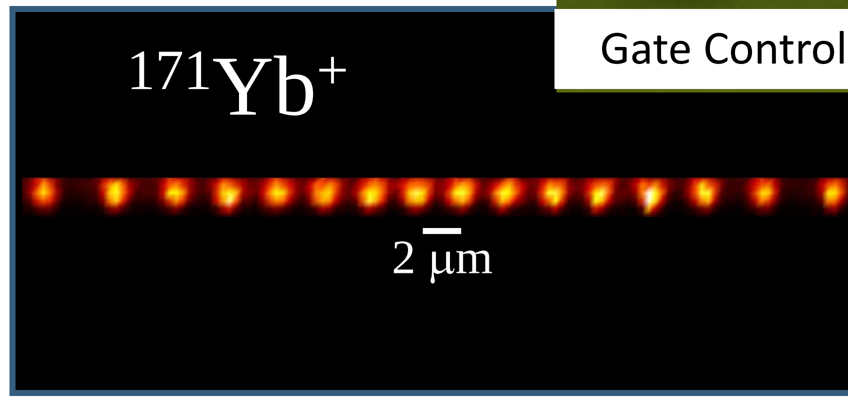
University of Maryland Institute for Advanced Computer Studies

Calibration

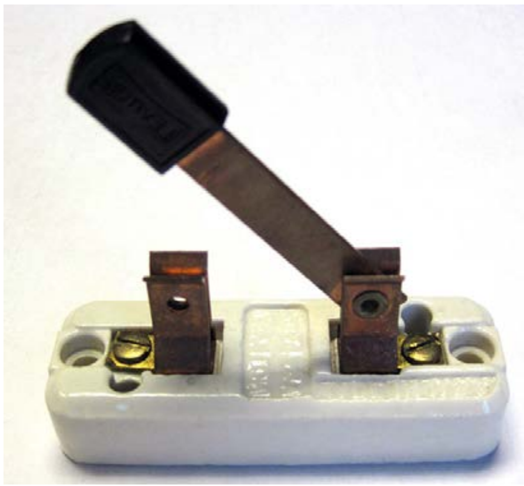


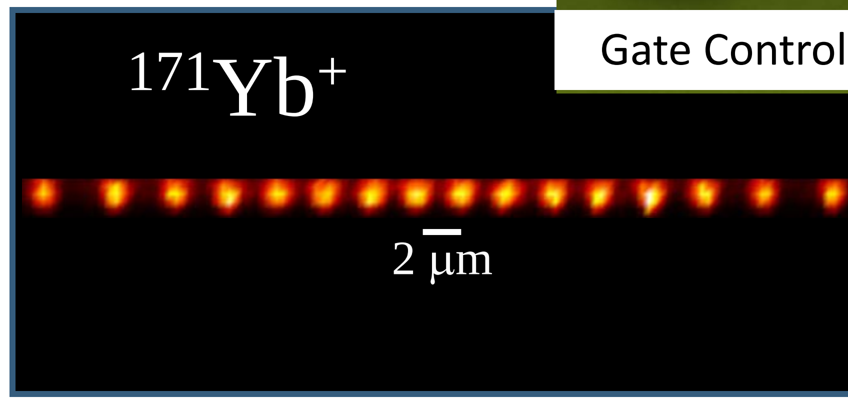
Gate Control



[Monroe Lab]

Calibration





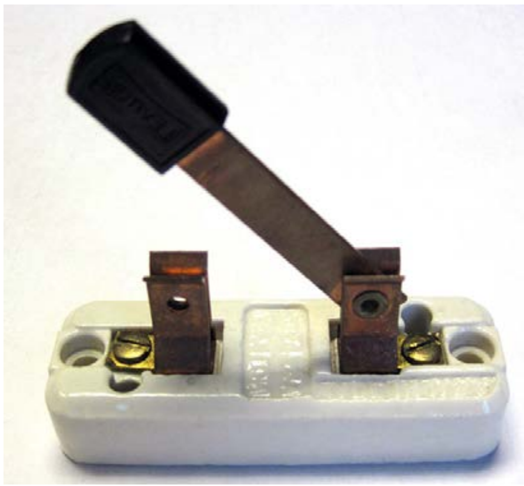
[Monroe Lab]

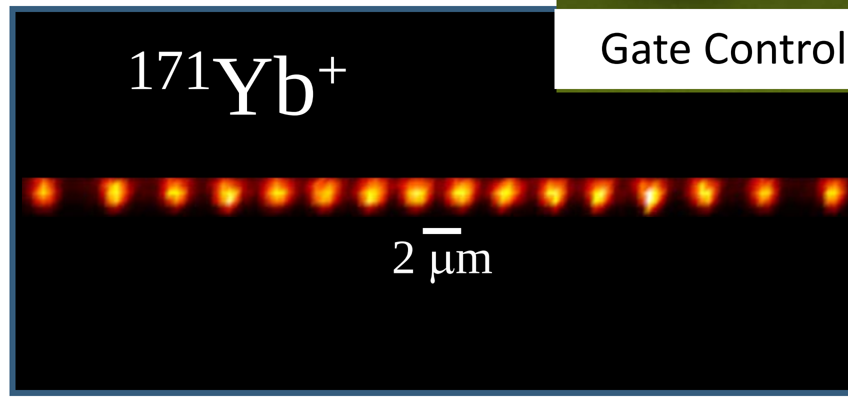
Gate Control

- All gates have errors
- State preparation has errors
- Measurements has errors

Calibration

Gate Control





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Want to quickly determine controllable errors, and then tune to fix.

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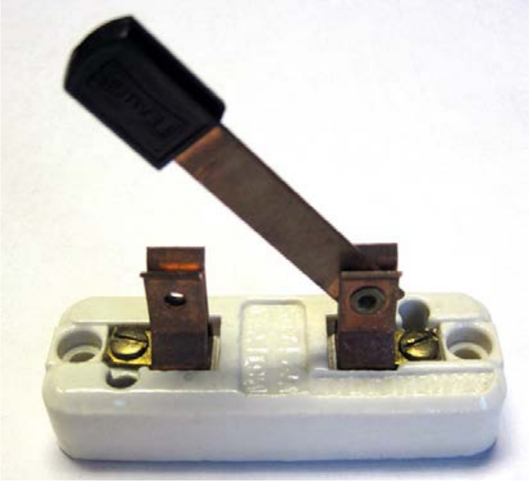

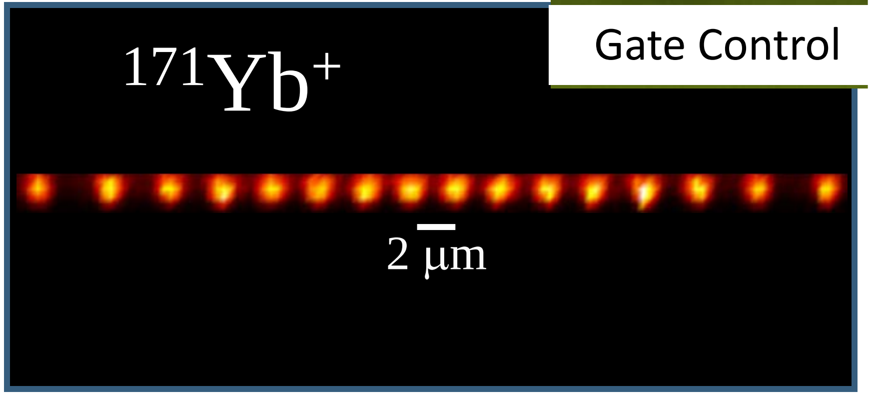

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Robust Phase Estimation

Want to quickly determine controllable errors, and then tune to fix.

Control Errors

- X-rotation, Y-rotation universal

- Rotation errors
  - X-rotation should be $\frac{\pi}{4}$, instead is $\frac{\pi}{4} + \alpha$
  - Y-rotation should be $\frac{\pi}{2}$, instead is $\frac{\pi}{2} + \epsilon$

- Error in angle between axes of rotation
  - should be $\frac{\pi}{2}$, instead is $\frac{\pi}{2} + \theta$

Robust Phase Estimation

Gate Control

Robust Phase Estimation

Gate Control

Compared to ad hoc Rabi – Ramsey sequences:

- ❑ Optimal efficiency (Heisenberg scaling)
- ❑ Robust to state prep and measurement noise
- ❑ Just as easy to implement
- ❑ Easy to analyze

Robust Phase Estimation

Gate Control

Compared to Randomized Benchmarking:

- Gate specific debugging information

Robust Phase Estimation

Gate Control

Compared to Gate Set Tomography:

- ❑ Stay Tuned!

Robust Phase Estimation

Suppose have uncalibrated universal gate set: $\widetilde{U}_X, \widetilde{U}_Y$

We run experiments of the form:

- $\rho_0 \to S_\theta\left(\widetilde{U}_X, \widetilde{U}_Y\right)^k \to M_0$ $\xrightarrow{\text{Probability of success}}$ $\dfrac{1+\cos k\theta}{2} + \delta_{k1},$
- $\rho_0 \to S_\theta\left(\widetilde{U}_X, \widetilde{U}_Y\right)^k \to M_+$ $\longrightarrow$ $\dfrac{1+\sin k\theta}{2} + \delta_{k2}$

Robust Phase Estimation

Suppose have uncalibrated universal gate set: $\widetilde{U}_X, \widetilde{U}_Y$

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θ is directly related to rotation error or axis error

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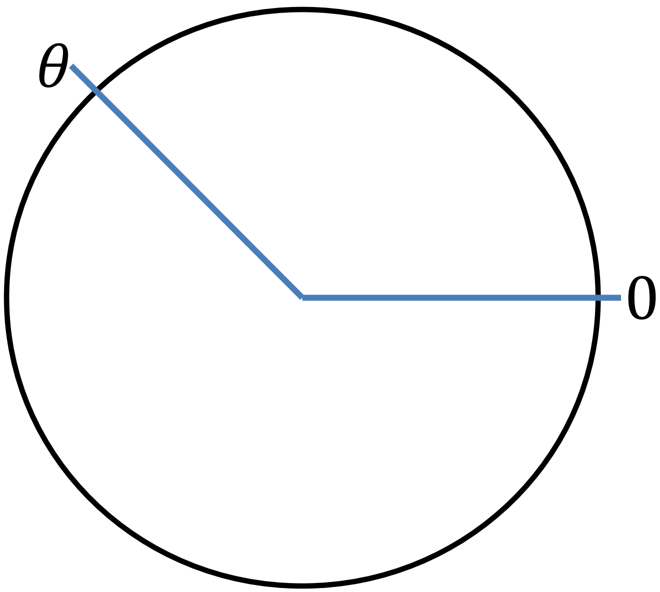
δ is related unknown state preparation, measurement, or non-unitary errors

Robust Phase Estimation

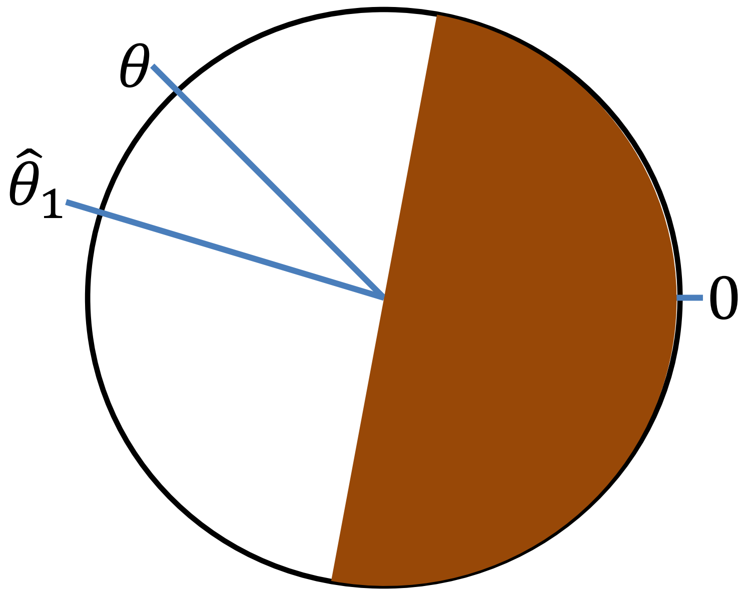


Can sample from 2 binomial random variables with probability of "heads"

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

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

Robust Phase Estimation



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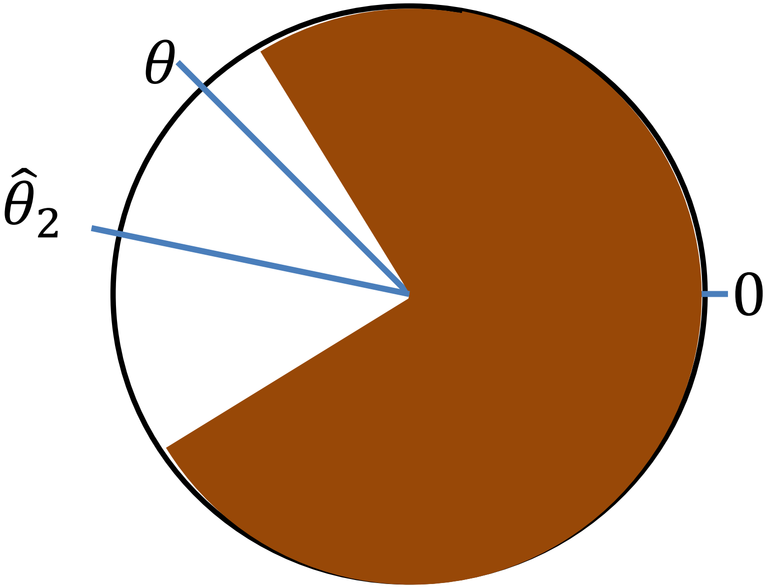

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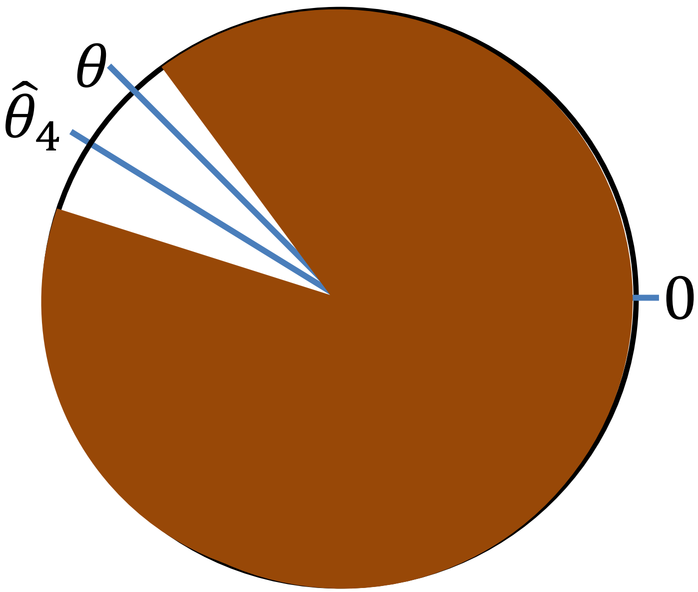

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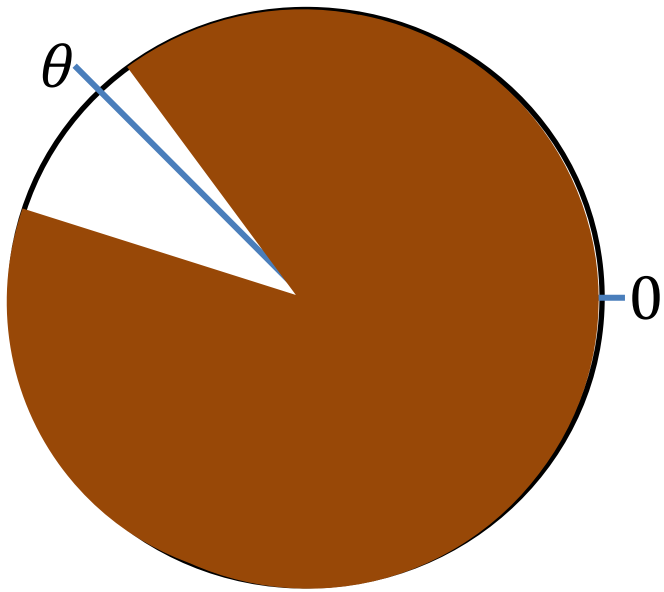
$k=1 \quad k=2 \quad k=4$

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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…need to take more samples to account for large δ

Additional Errors

All of the following errors simply contribute to δ errors

- Imperfect state preparation
- Imperfect measurement
- Additional errors like depolarizing errors

Can incorporate any error, as long as can bound how much that error will shift your outcome probability (and total shift is less than .35)

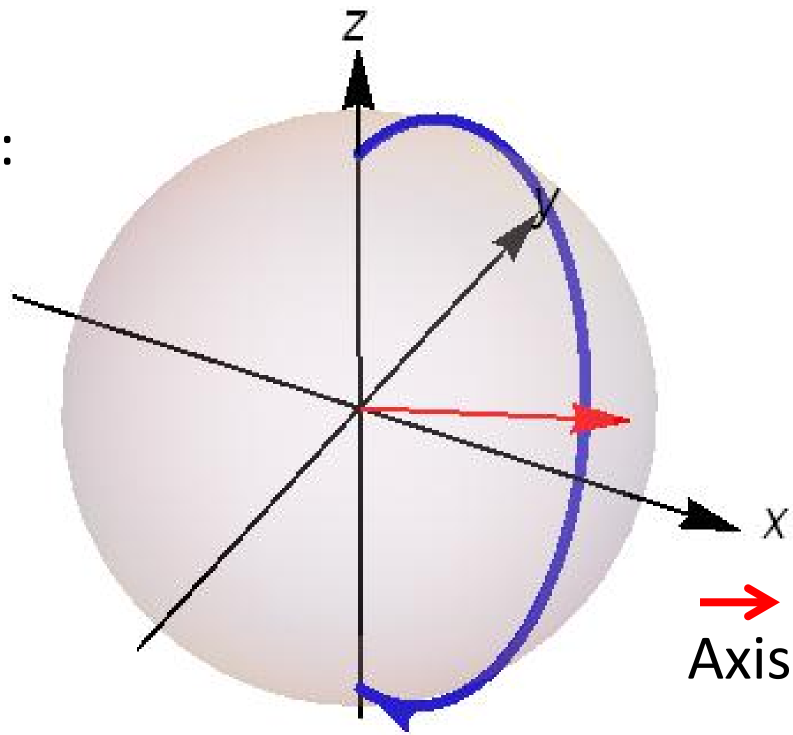
Try it Out!

- Numerical and Experimental Data in Next Talk
- RPE-Experimental branch on pyGSTi github repository – pygsti.info

Control Errors

Amplitude of Rotation:

"Amplitude Error" (error in amount of rotation)

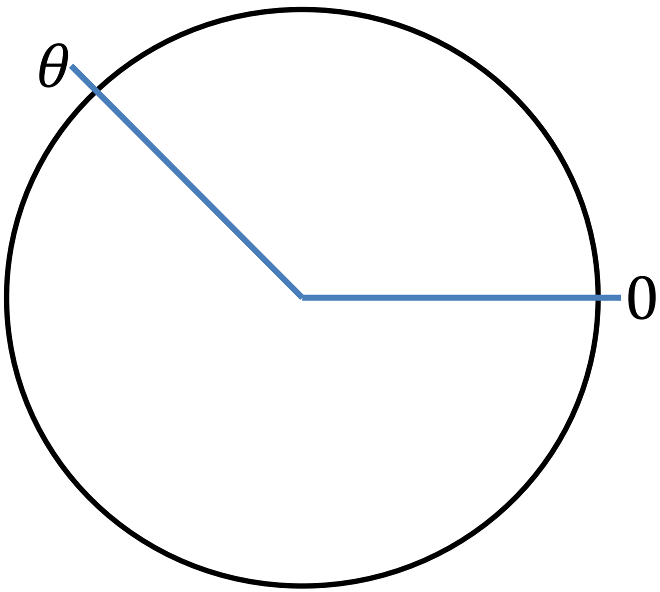


Unitary $\widetilde{U}$

Axis of Rotation

"Off-Resonance Error" (error in axis of rotation)

Robust Phase Estimation



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