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Hyper-accuracy and Error-Scaling in Gate Set Tomography

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U.S. DEPARTMENT OF ENERGY

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Outline

- Old results:
  - Achieving calibration-free quantum tomography.
    (Linear gate set tomography)

- New results:
  - Through the usage of short, repeated gate sequences, unprecedented accuracy in gate set estimation (per element error rate of 10^{-5} with scaling better than $N^{-3.9}$) is achieved.

Towards true QIP

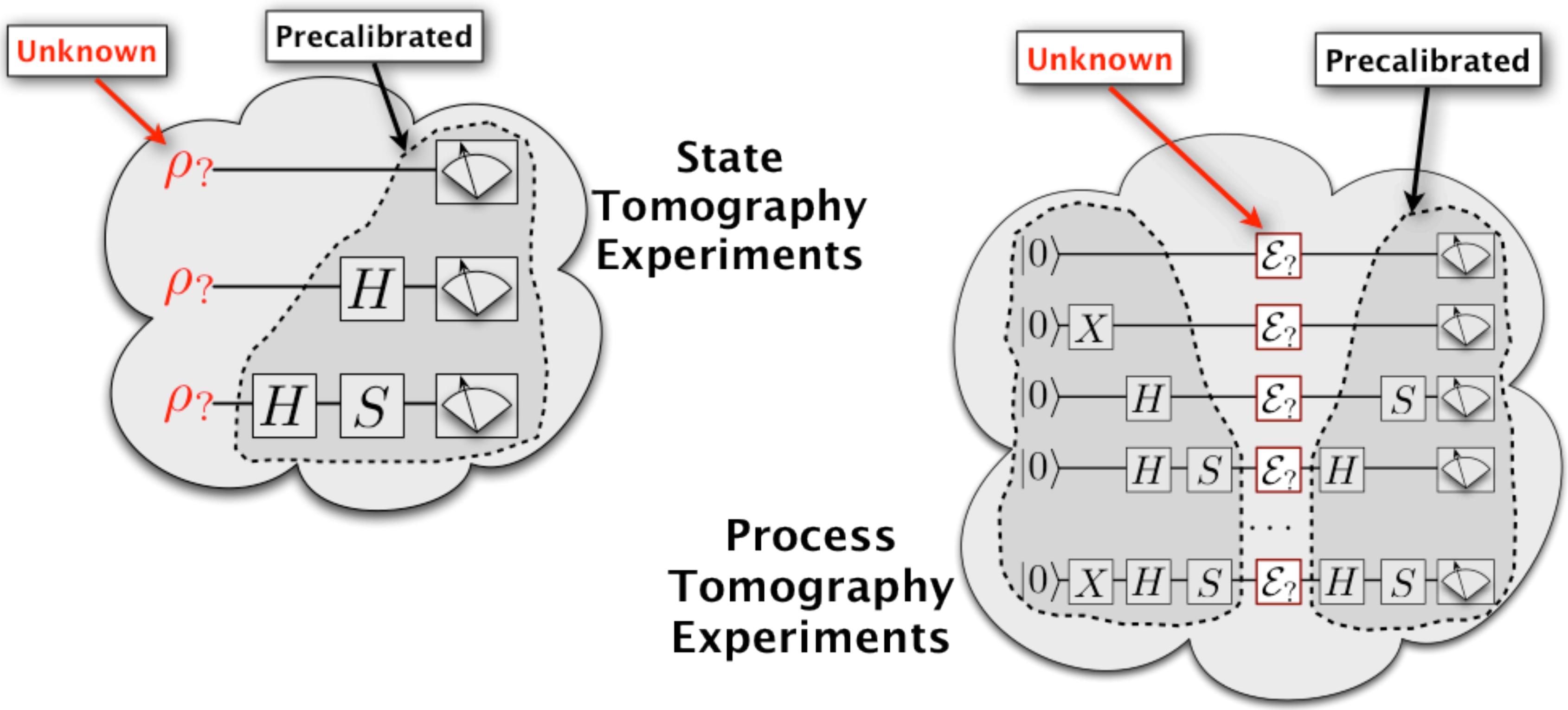
Want gate set $\mathcal{G} \overset{e.g.}{=} \{\mathrm{I}, \mathrm{X}_{\pi/2}, \mathrm{Y}_{\pi/2}\}$

$$G_{ij}^{est} = G_{ij}^{exp} + \varepsilon_{ij}$$

Goal of tomography:

Make ε_{ij} as small as possible as cheaply as possible.

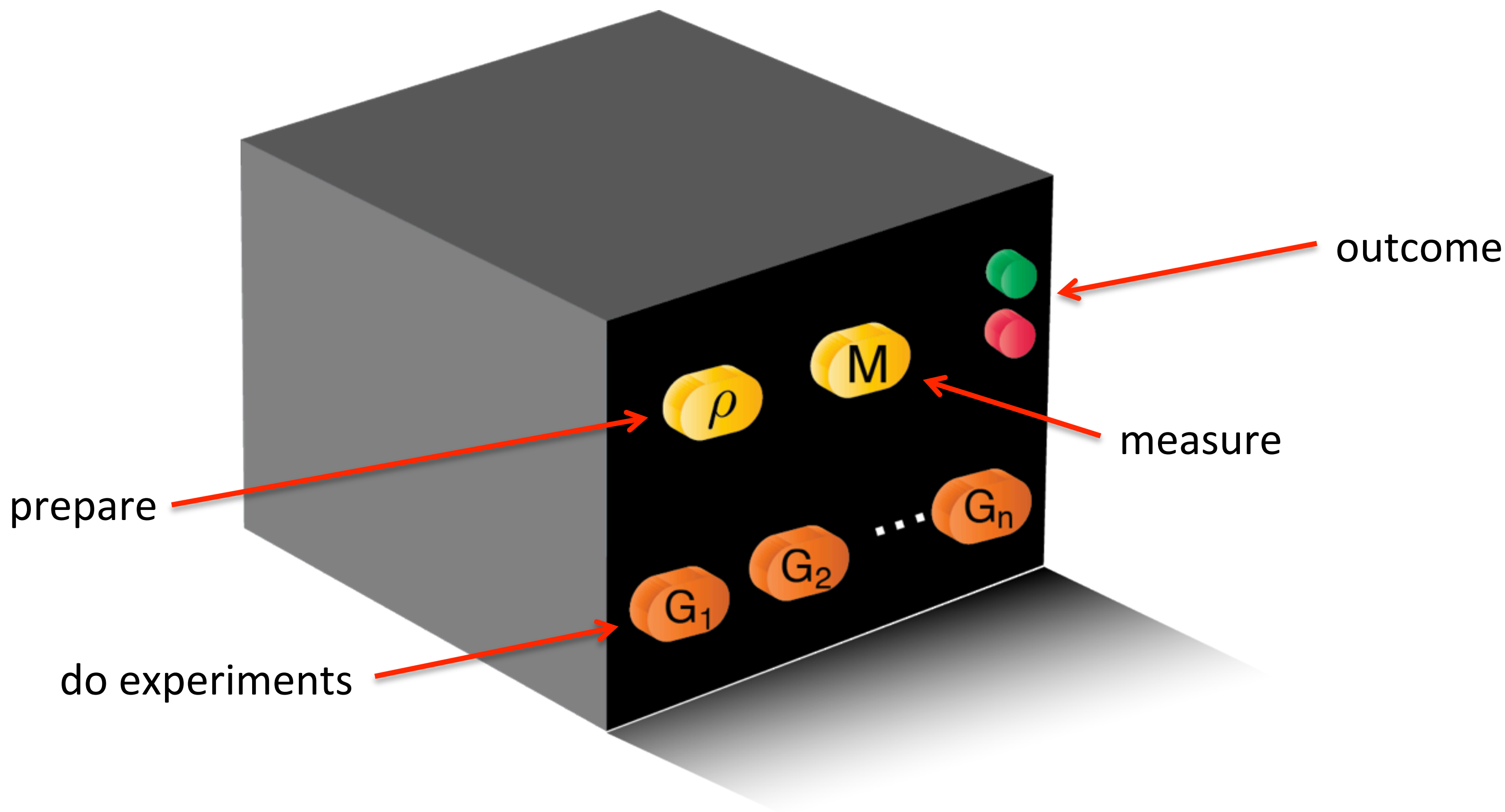
The problem with tomography



Critical problem: relies on precalibrated reference frames that don't really exist in hardware!

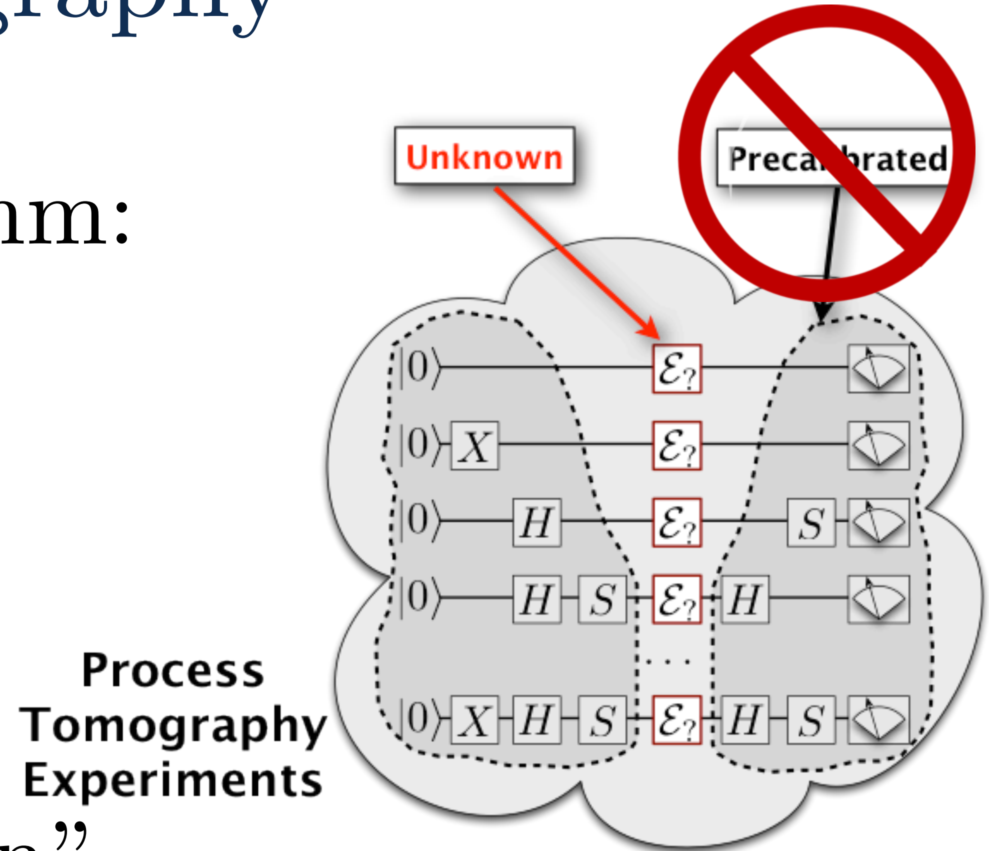
Goal: Calibration-free tomography.

“Black box picture” of quantum information processor



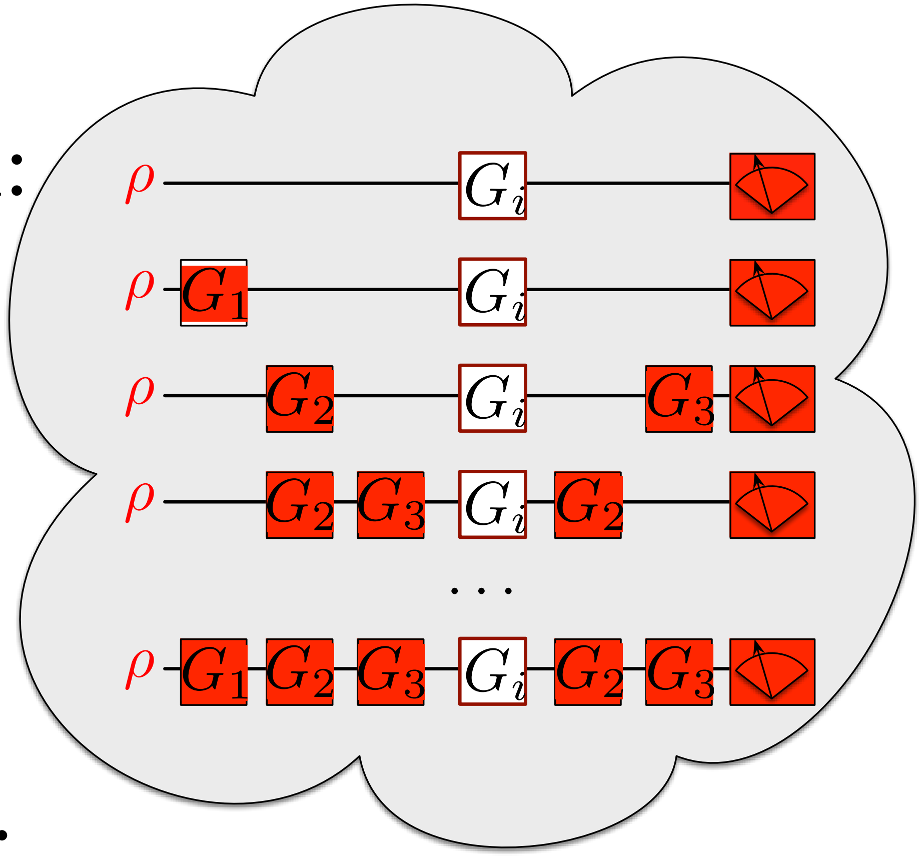
Gate Set Tomography

- Simplest algorithm: Linear Inversion (LGST)
- "Process tomography without calibration".

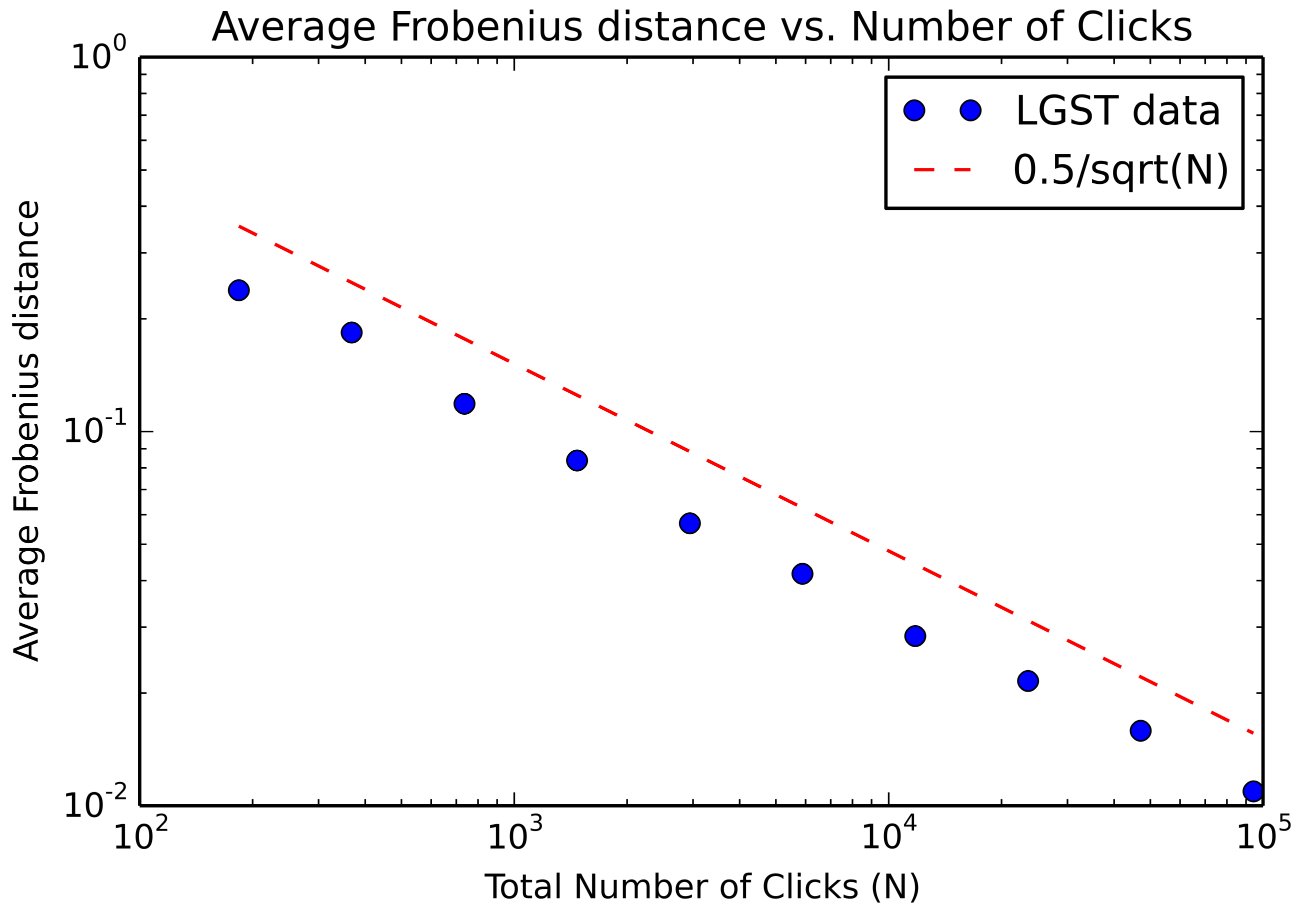


Gate Set Tomography

- Simplest algorithm: Linear Inversion (LGST)
- "Process tomography without calibration".
- Linear algebra → gate set
- arXiv:1310.4492



LGST on simulated data



Limited by $\frac{1}{\sqrt{N}}$. Can we do better?

Can we achieve hyper-accuracy?

To achieve high accuracy, need to amplify small parameters.

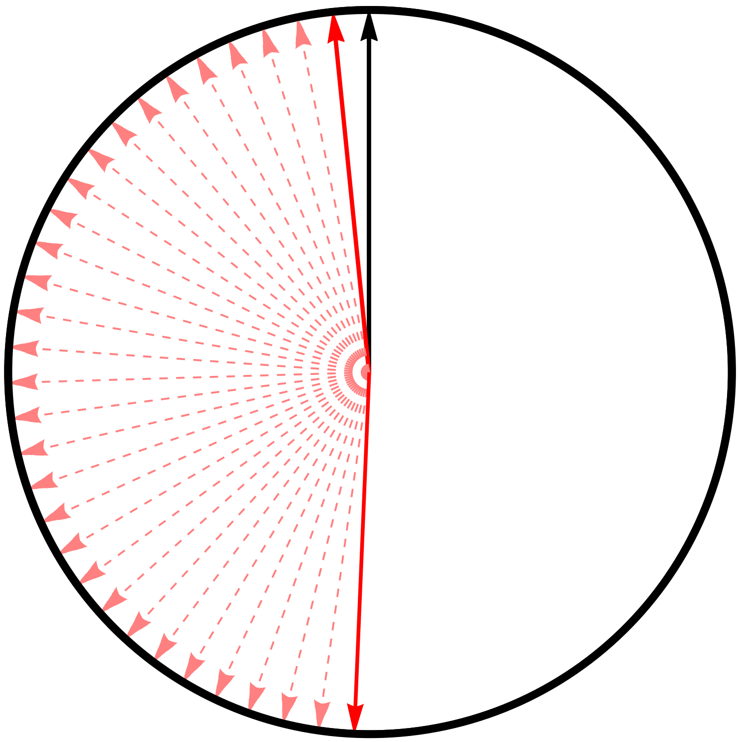
Ex: $G = e^{-i\theta\sigma_z}$ $\theta << 1$

To achieve accuracy $\pm\theta$:

Push G once, measure.
Repeat N=O($1/\theta^2$) times.

OR

Push G O($1/\theta$) times, measure.
Repeat N=O(1) times.



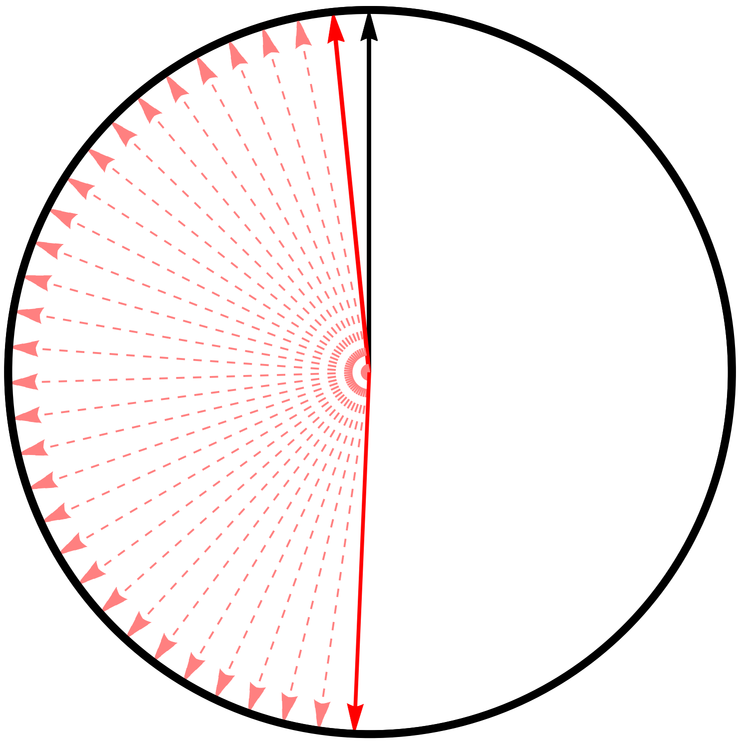
Can amplify coherent errors!

Can we achieve hyper-accuracy?

What if we don't know θ?

Proceed iteratively: Estimate G^L for L=1, 2, 4, 8...L_{max}

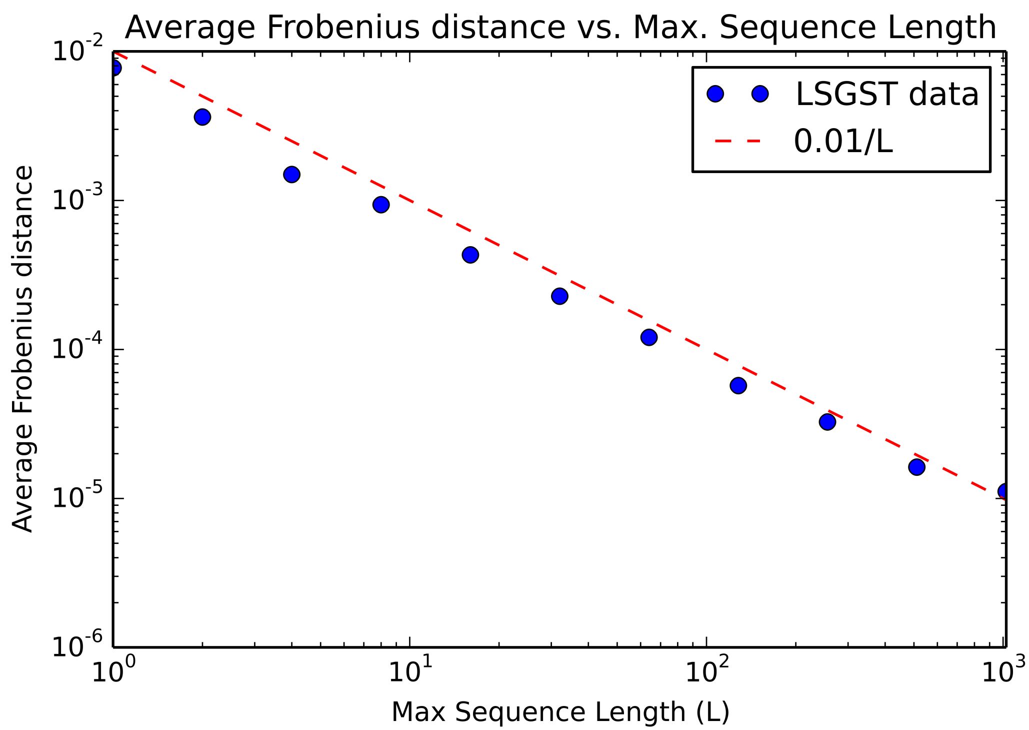
Can use this in GST framework;
Need to repeat other sequences
(e.g. G_1G_2) to amplify *all* gate
parameters/errors, e.g., tilt error.



Can iteratively use LGST estimates
on successively longer repetitions
of gate sequences to estimate gate set
with high accuracy.

How well does this work?

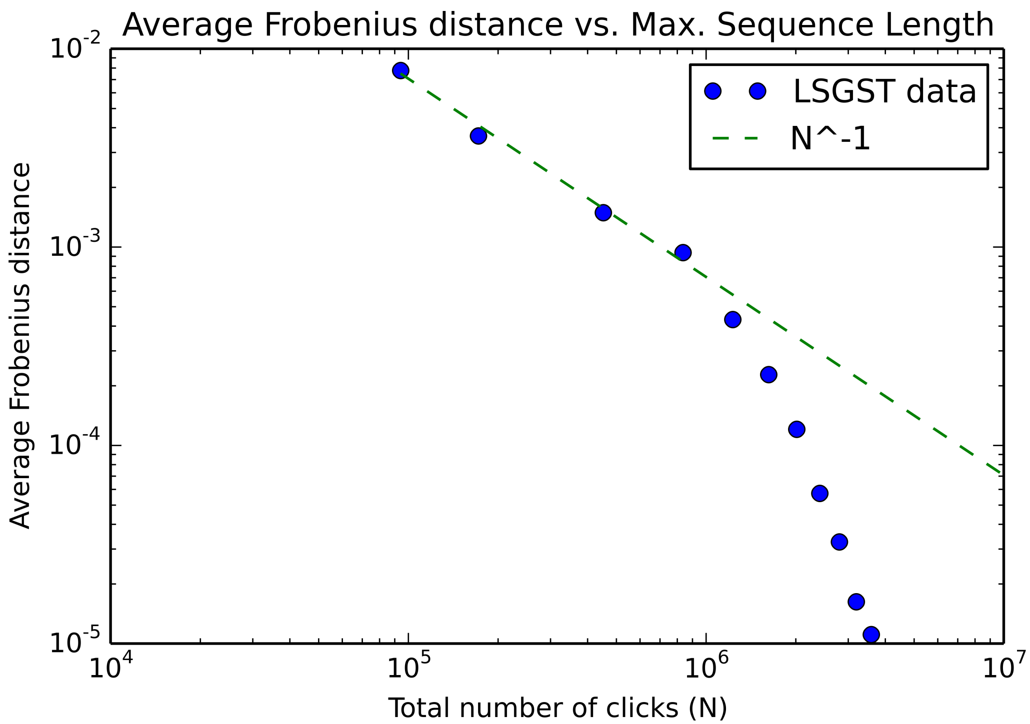
Can we achieve hyper-accuracy?



$$\text{Error scales as } \sim \frac{1}{L}!$$

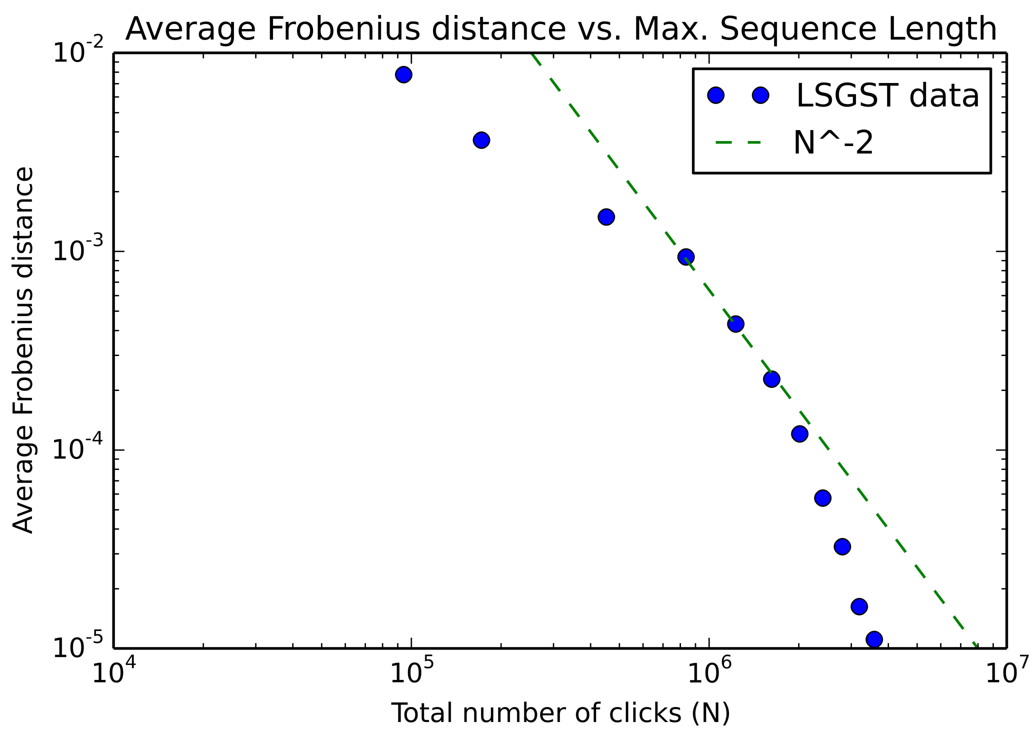
Can we achieve hyper-accuracy?

$$N^{-1}$$

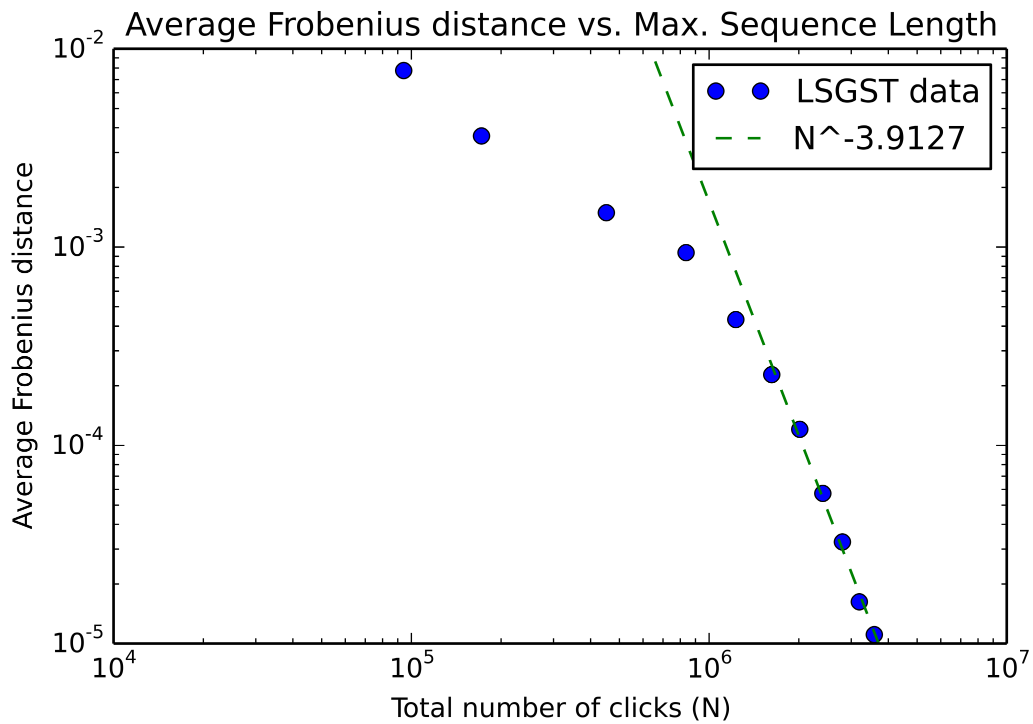


Can we achieve hyper-accuracy?

$$N^{-2}$$



Can we achieve hyper-accuracy?



$N^{-3.9}$

Scaling *at least* as good as $N^{-3.9}$!

Maybe as good as e^{-N}?

Conclusions

Problem	Solution
Need to characterize gates.	Quantum process tomography
QPT relies on precalibrated gates.	Linear gate set tomography (LGST)
LGST scales no better than QPT.	Extended linear gate set tomography → Error scales better than $N^{-3.9}$
You want to see experimental demonstration.	Stick around for Erik's talk (coming next!).