Mitigating time-varying noise in surface code magic state factories

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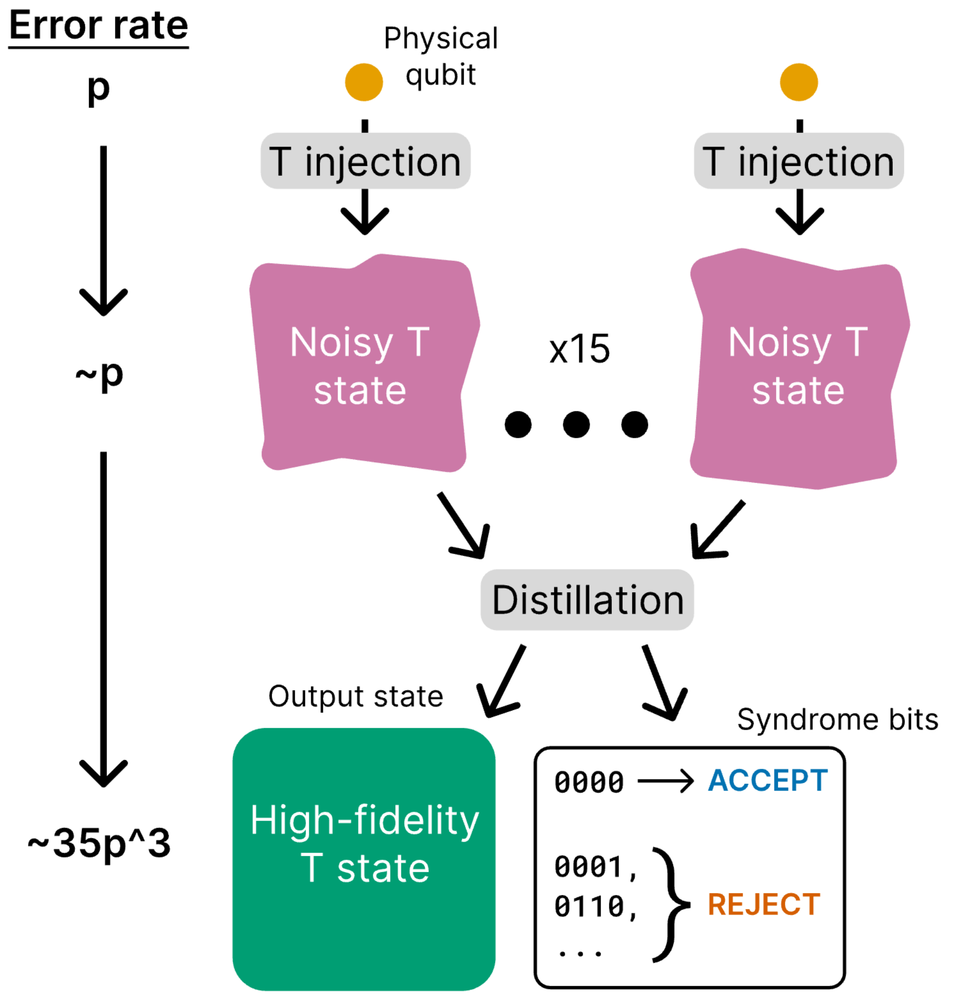
* denotes equal contribution

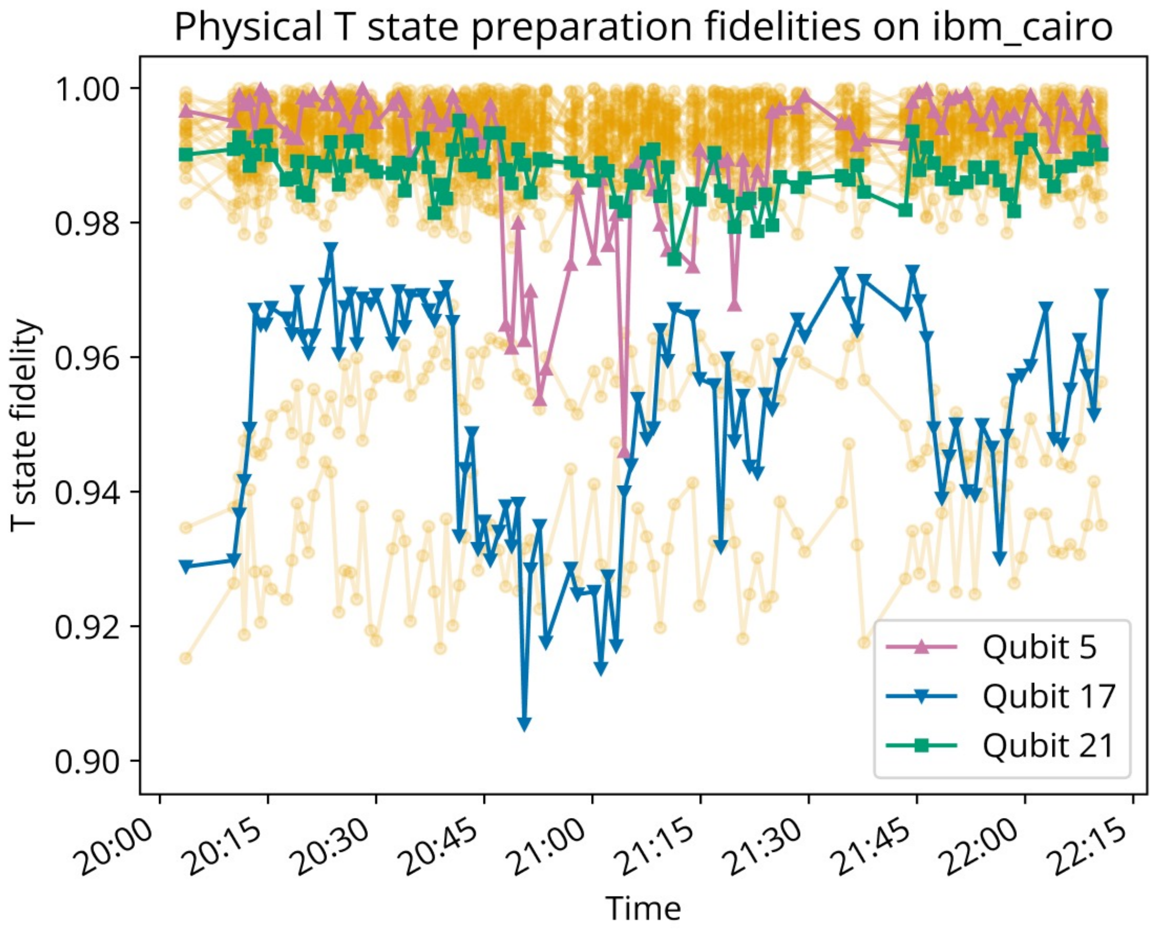
Background: magic state distillation

- Early fault-tolerant algorithms: required T state infidelity at least $\sim 10^{-7}$
- *Magic state distillation* converts 15 *physical* T states to 1 high-fidelity *logical* T with output error $35p^3$
- One bad T can disrupt an entire computation; important that T fidelity is what we expect!



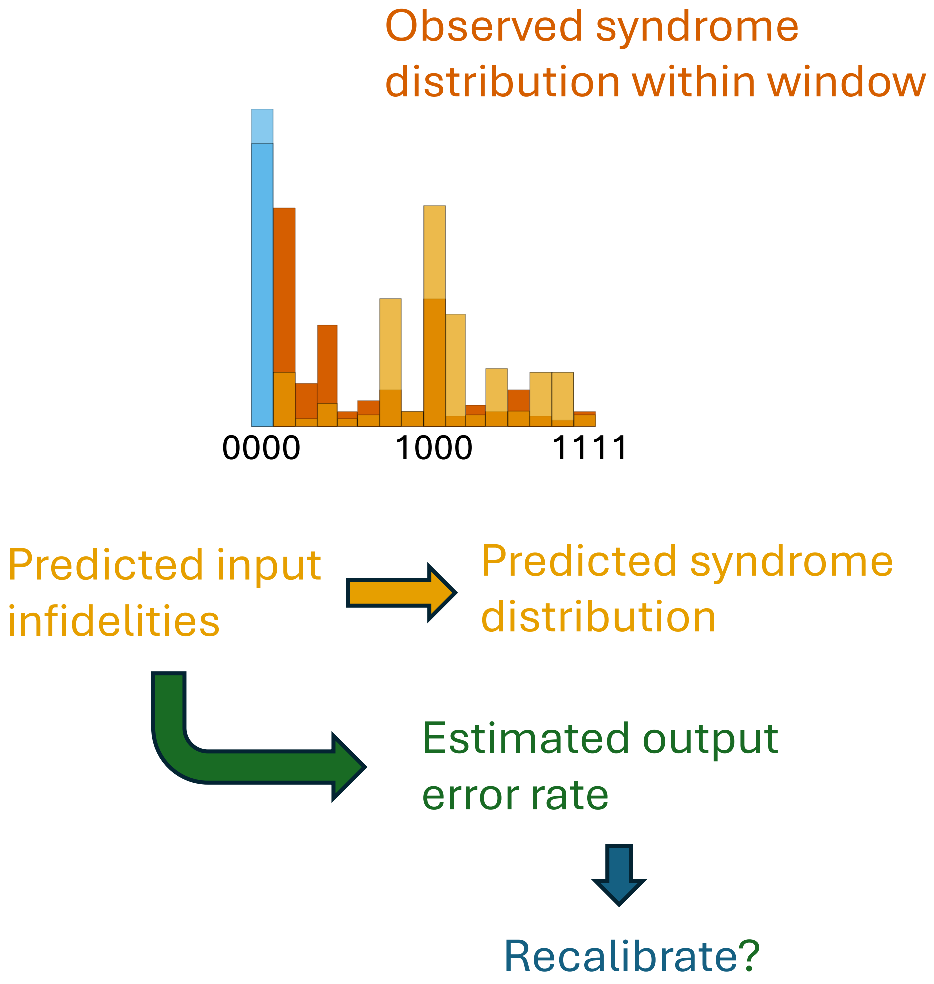
Real devices are highly unpredictable

- Noise fluctuates on the individual qubit level
- IBM recalibrates daily, and Google recalibrates before every experiment
- What if we have a fault-tolerant program running for many hours or even days?
- Goal: *guarantee* distilled T fidelity under fluctuating device noise

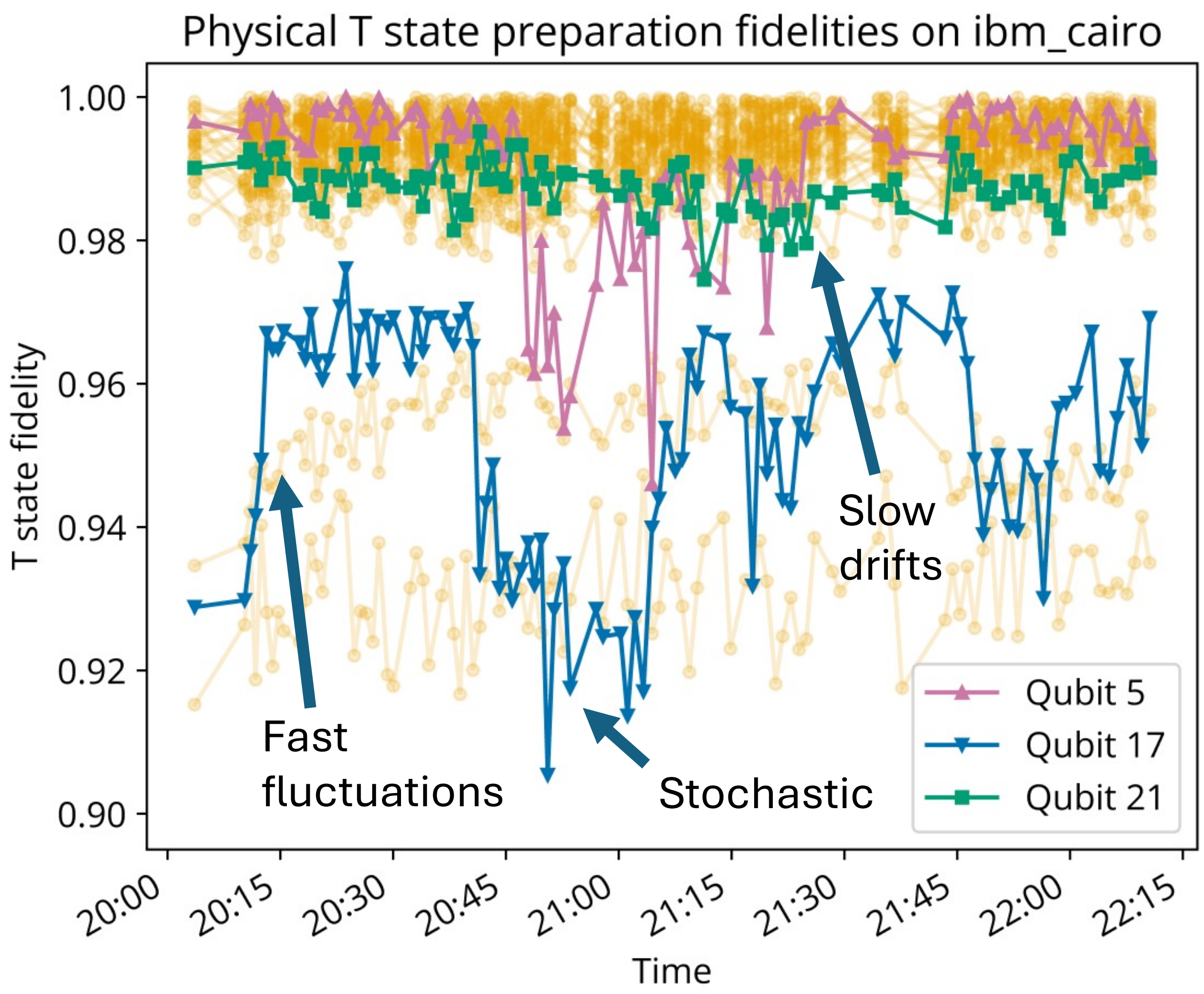


Insight: syndrome bits tell us which input states are faulty

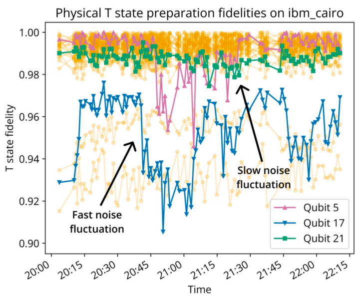
- Each unique input logical T error triggers a unique set of syndrome bits
- Estimation method:
  - Observe syndrome bits over some window
  - Find assignment of *input* T infidelities that best explains observed syndrome bit distribution
  - Calculate estimated *output* infidelity
- 2 tunable parameters: window size and recalibration threshold



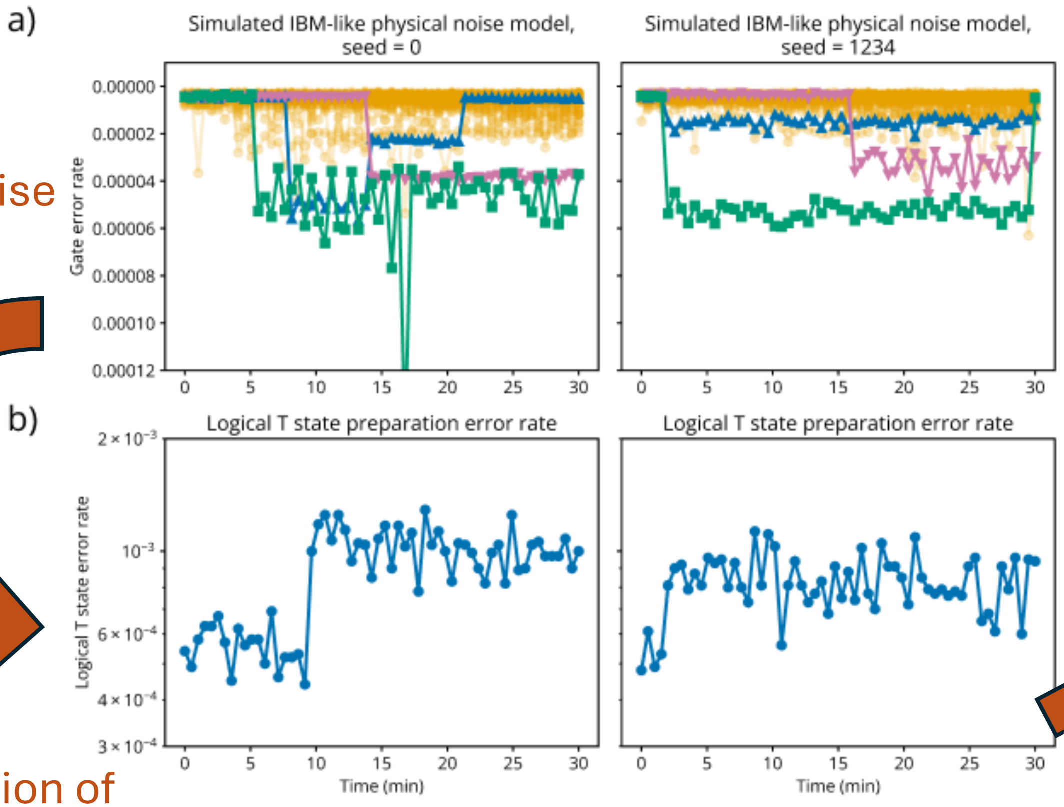
Designing an expressive noise model



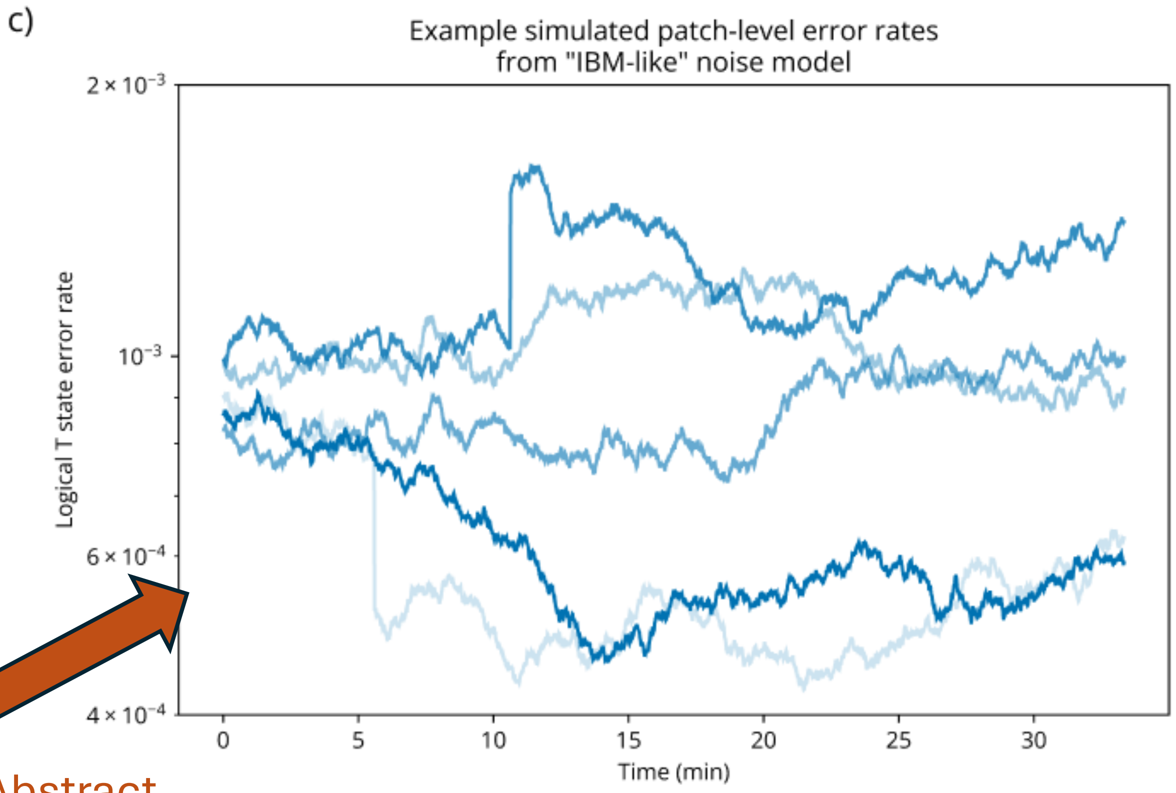
Designing an expressive noise model



Detailed physical qubit noise model

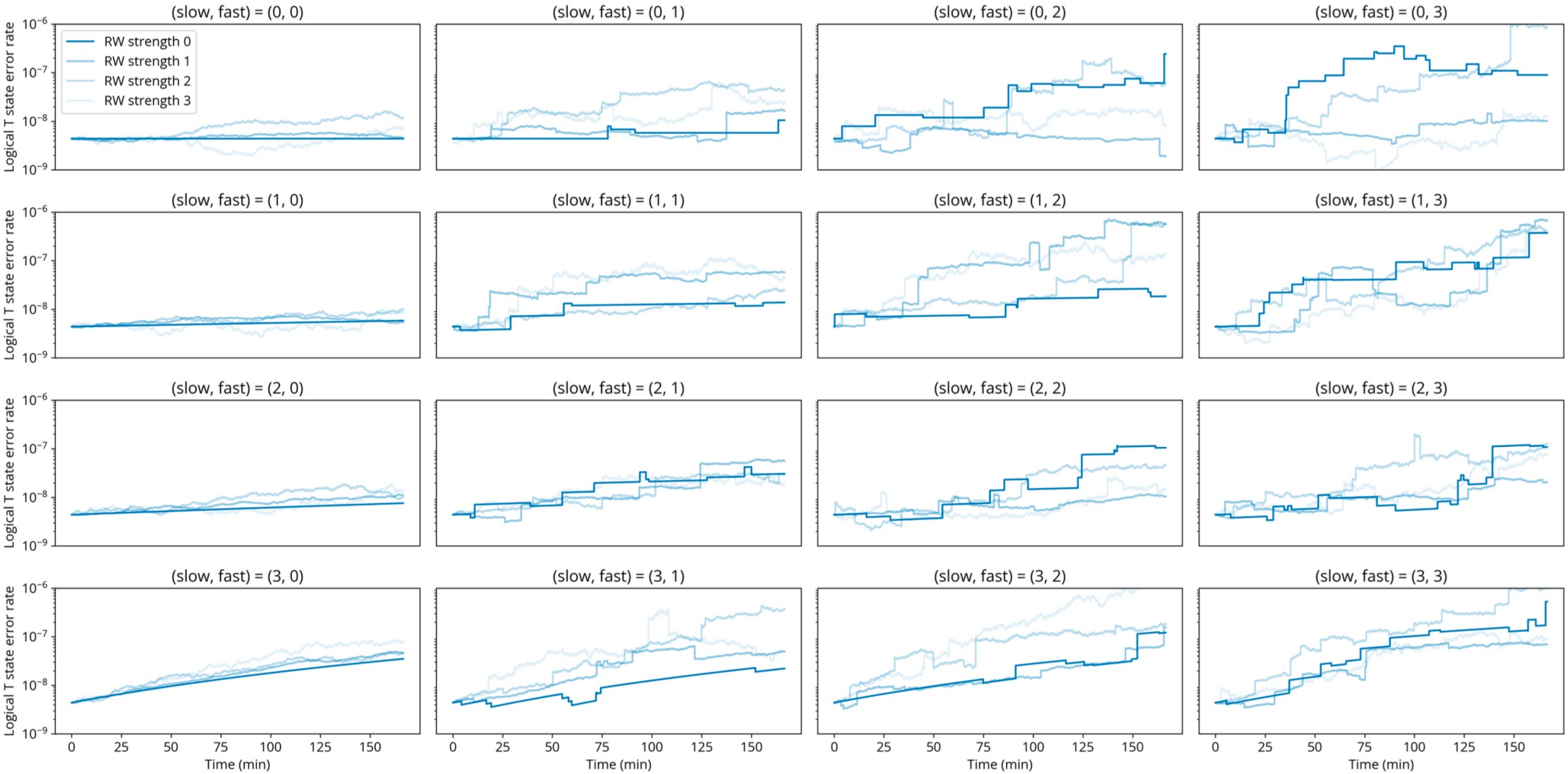


Stim simulation of noisy magic state injection

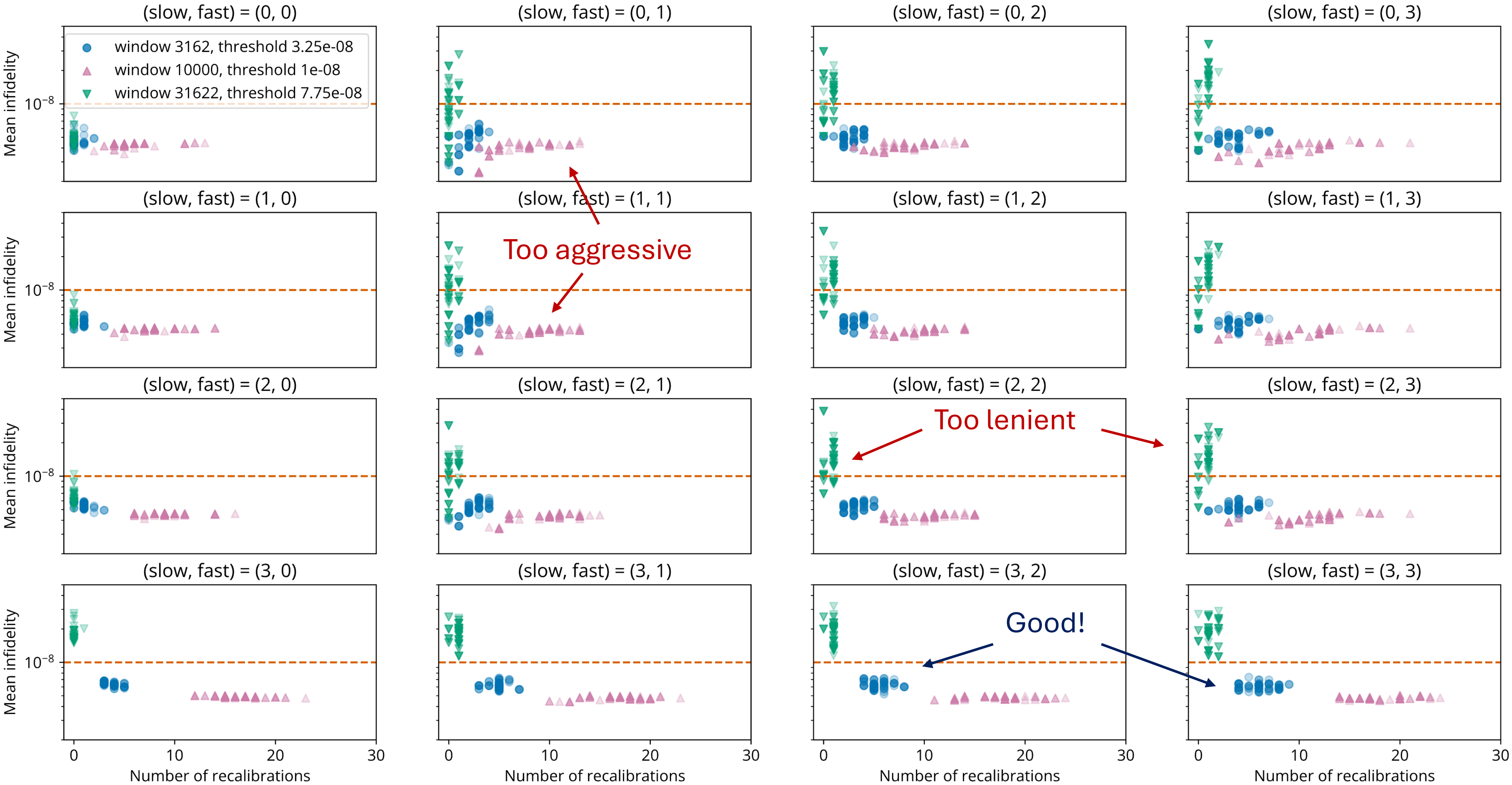


Abstract logical-level noise model

Noise models

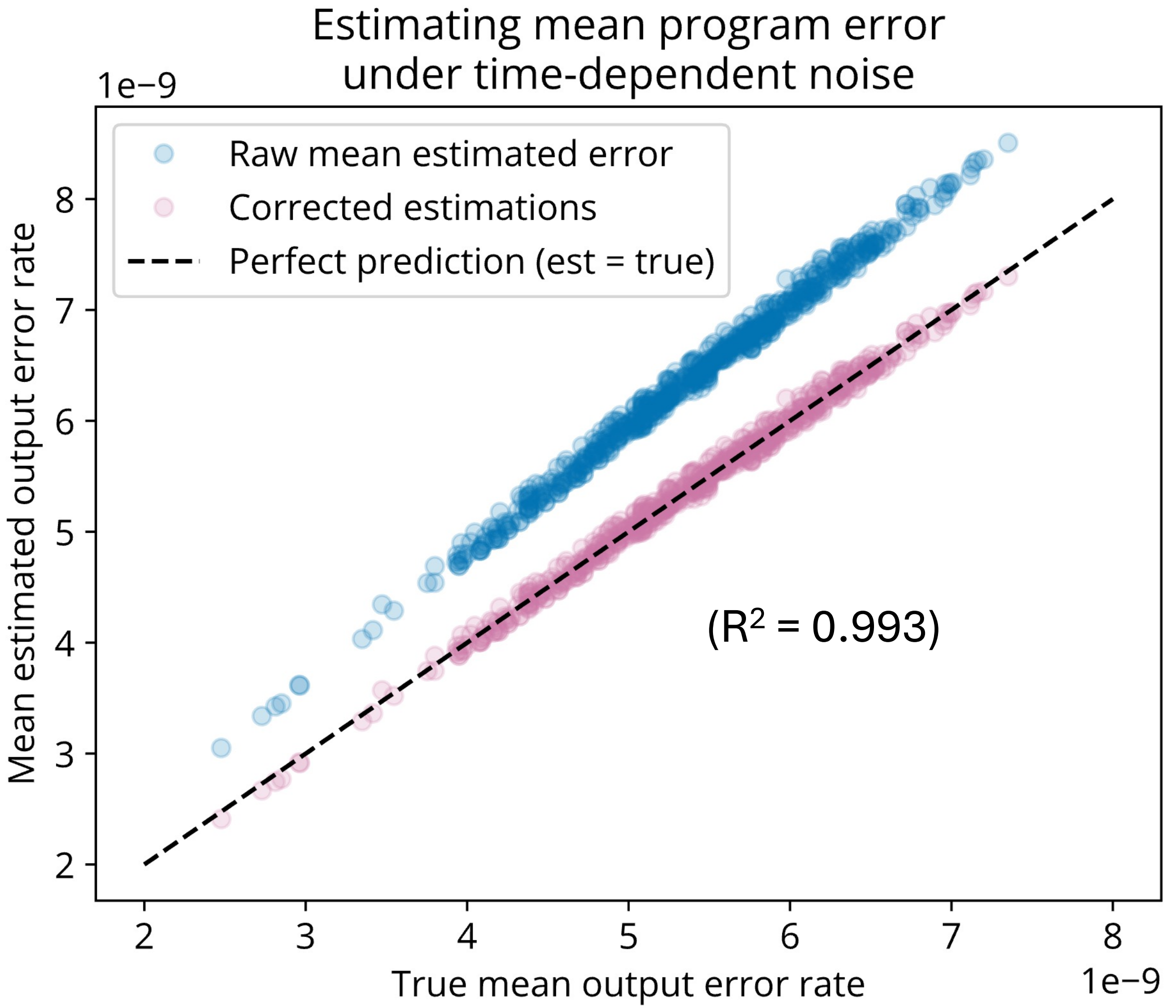


Triggering recalibrations from estimations



Verifying program performance

- We can calculate the *mean* estimated infidelity over all windows in the program
- Useful to build confidence in a program result after completion



Conclusion

- We have developed a *minimal-overhead* method to estimate the fidelity of distilled T states
- Over a wide range of noise models, our estimator can be used to trigger *targeted recalibrations* to maintain T fidelity guarantees
- On a program level, we can estimate the overall mean T fidelity to *verify program correctness*

Thanks!