Pasqal

Magic state cultivation compiled for neutral atoms

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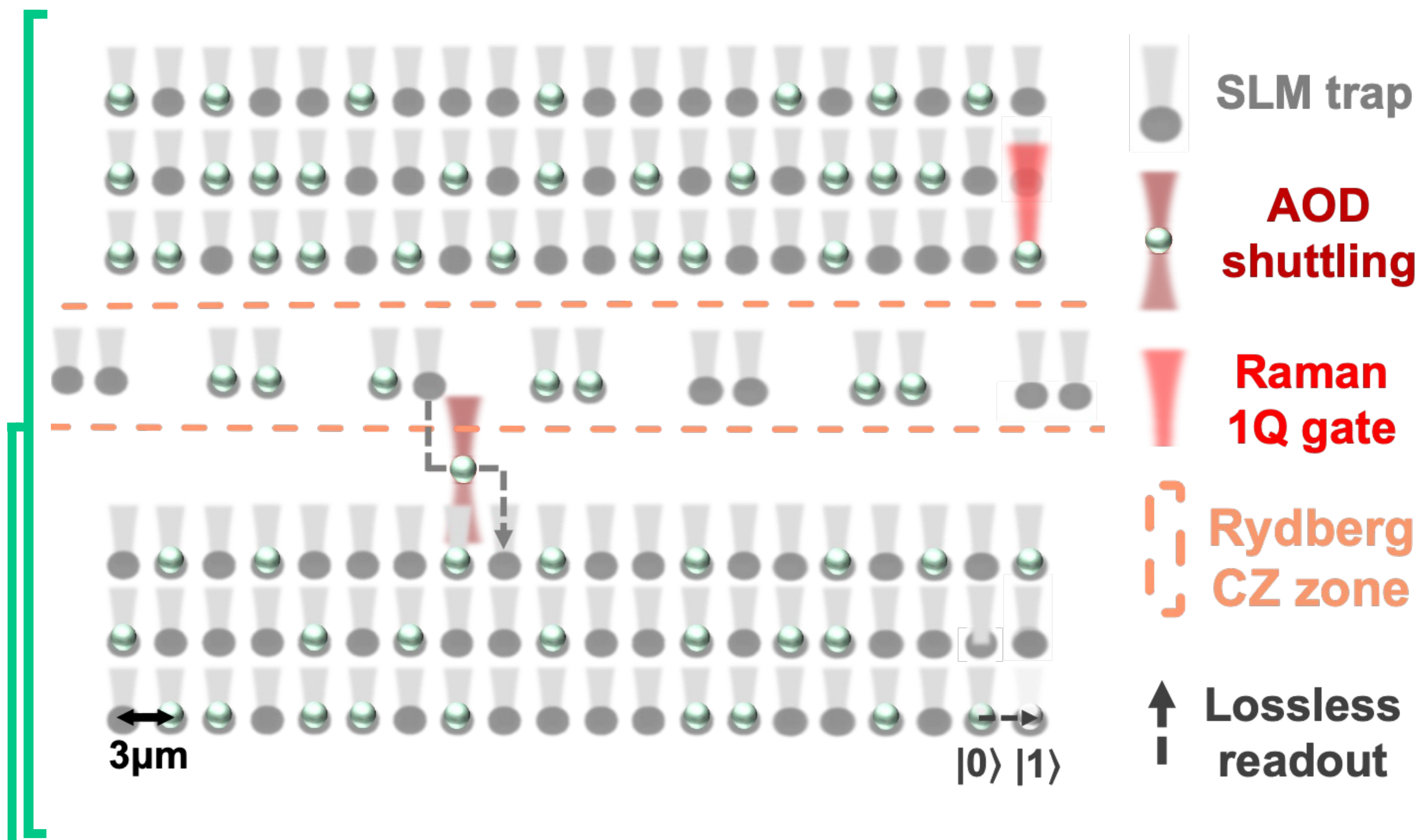
Abstract - *While neutral atom platforms have demonstrated rapid scaling and high-fidelity transversal operations, the robust implementation of arbitrary logical unitary remains a critical bottleneck. This work presents a comprehensive compilation and numerical analysis of the magic state cultivation protocol, specifically the Steane code cultivation scheme, tailored for a zoned-architecture neutral atom processor. By employing state-of-the-art compilation tools to map high-level circuits to atomic trajectories and hardware-native operations, we evaluate the protocol's performance under a realistic, hardware-tailored Pauli noise model. For current-generation hardware noise parameters, the ungrown cultivation protocol achieves a logical error rate of 10^{-4} with an acceptance rate of approximately 20%.*

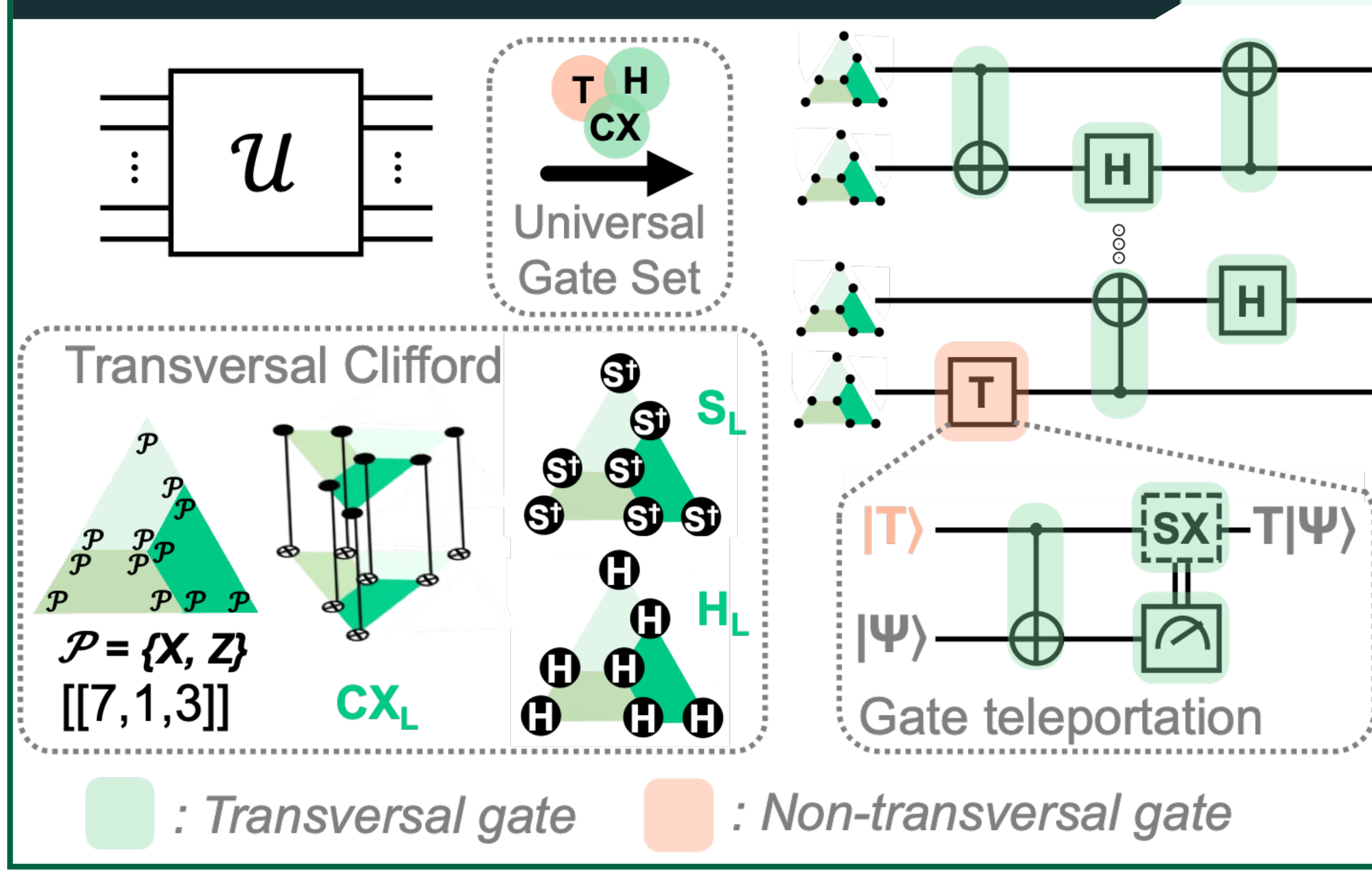
Near-term neutral-atom QPU

Zones and atomic operations [3][4]



Magic states for Universal FTQC

Arbitrary unitary $\mathcal{U}$ compilation into color code logical operations

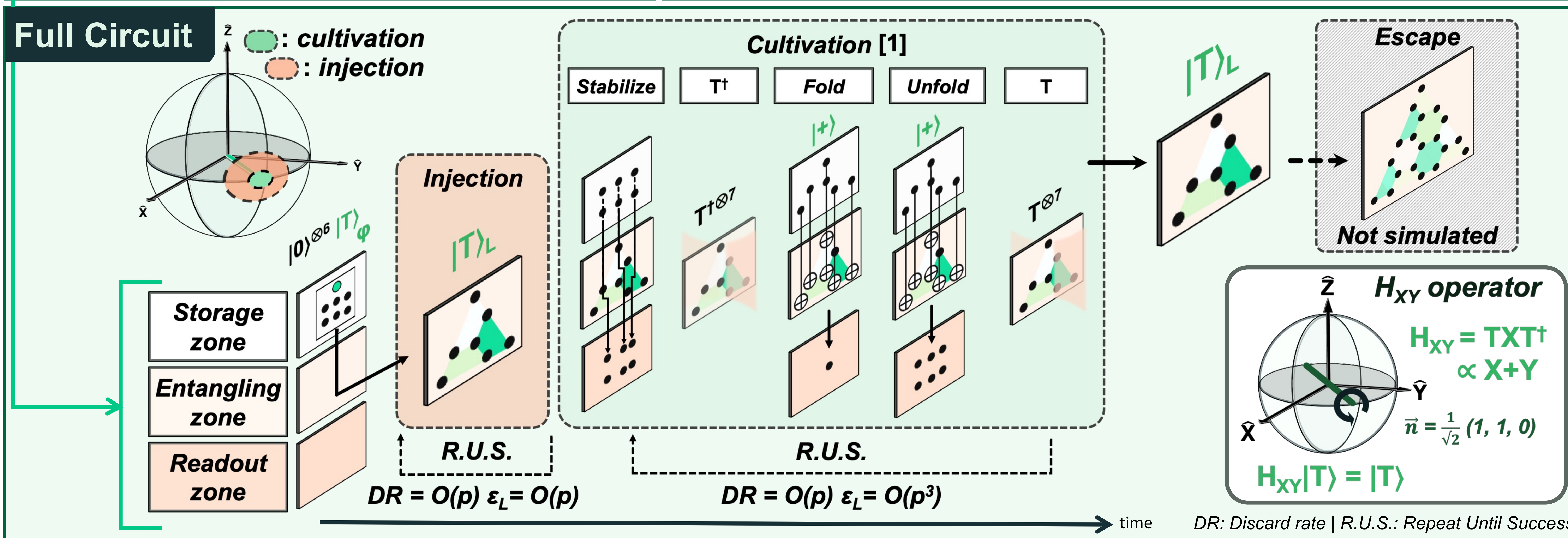


Leading strategy for achieving UFTC:

- ❑ transversal Clifford,
- ❑ high-fidelity (magic) |T⟩ states.

Gate teleportation is paramount in this scheme, enabling fault-tolerant T gate application through **transversal** Clifford operations.

Full Circuit



DR: Discard rate | R.U.S.: Repeat Until Success

Results and discussion

Compilation aided by open-source tools like QMAP **[6]** to optimize atom moves, placement and scheduling.

LER ~ 10^{-4} @ ~20% acceptance

- distance-3 Steane code,
- current neutral-atom noise (s = 1).

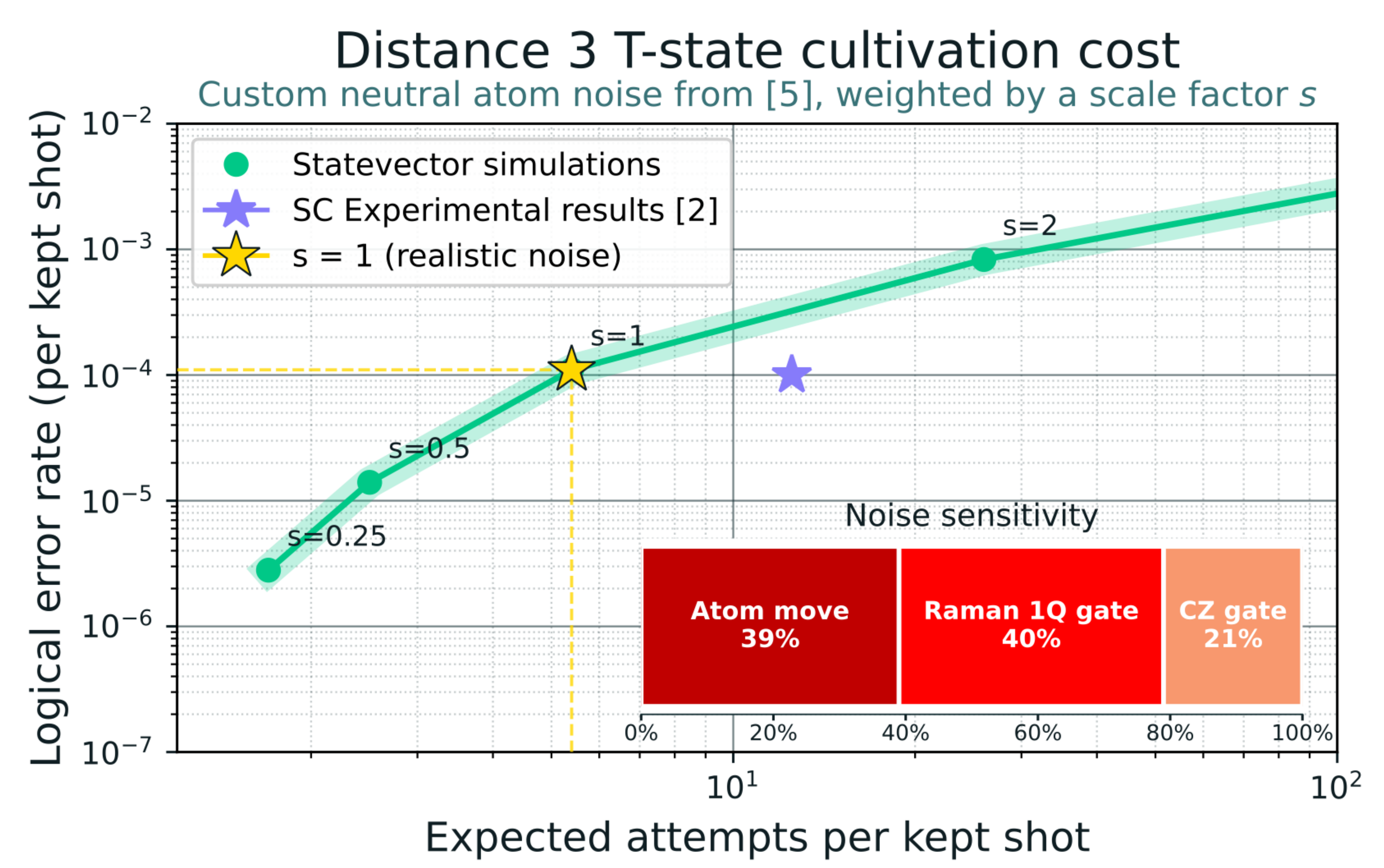
Same order of magnitude as the recent superconducting demo **[2]**, on a very different platform.

Dominant error channels (see below): CZ gate ≫ atom moves > 1Q / idling.

Cubic suppression
LER ∝ p^3 confirmed → halving physical error rate ⇒ ~10× lower LER.

Caveats:

1. Pauli-only noise (no loss / leakage / coherent errors)
2. feedback idealized as 1 idle step
3. ungrown stage only: escape into a grown code remains the open bottleneck



Physical Operation	Error channel	Amplitude
Local 1Q-gate	Dep.	$4e^{-3}$
Global 1Q-gate	Dep.	$4e^{-4}$
Atom move	Pauli	$3e^{-5}$ (1, 1, 1e²)
Controlled-Z	Pauli	$1.5e^{-4}$ (p_{ZI}, p_{IZ}, p_{ZZ}: 10, else: 1)
Measurement	Pauli	($6e^{-3}$, 0, 0)
Idling	Pauli	$1e^{-7}$ (1, 1, 5)

References

[1] Gidney, et al. "Magic state cultivation: growing T states as cheap as CNOT gates." 2024
[2] Rosenfeld, et al. "Magic state cultivation on a superconducting quantum processor." 2025
[3] Bluvstein, et al. Logical quantum processor based on reconfigurable atom arrays. 2024
[4] Bluvstein, et al. "Architectural mechanisms of a universal fault-tolerant quantum computer." 2025
[5] Balewski, et al. "Compilation of Qcrank Encoding Algorithm for a Dynamically Programmable Qubit Array Processor." 2025
[6] Y. Stade, et al. "Routing-Aware Placement for Zoned Neutral Atom-based Quantum Computing," 2025