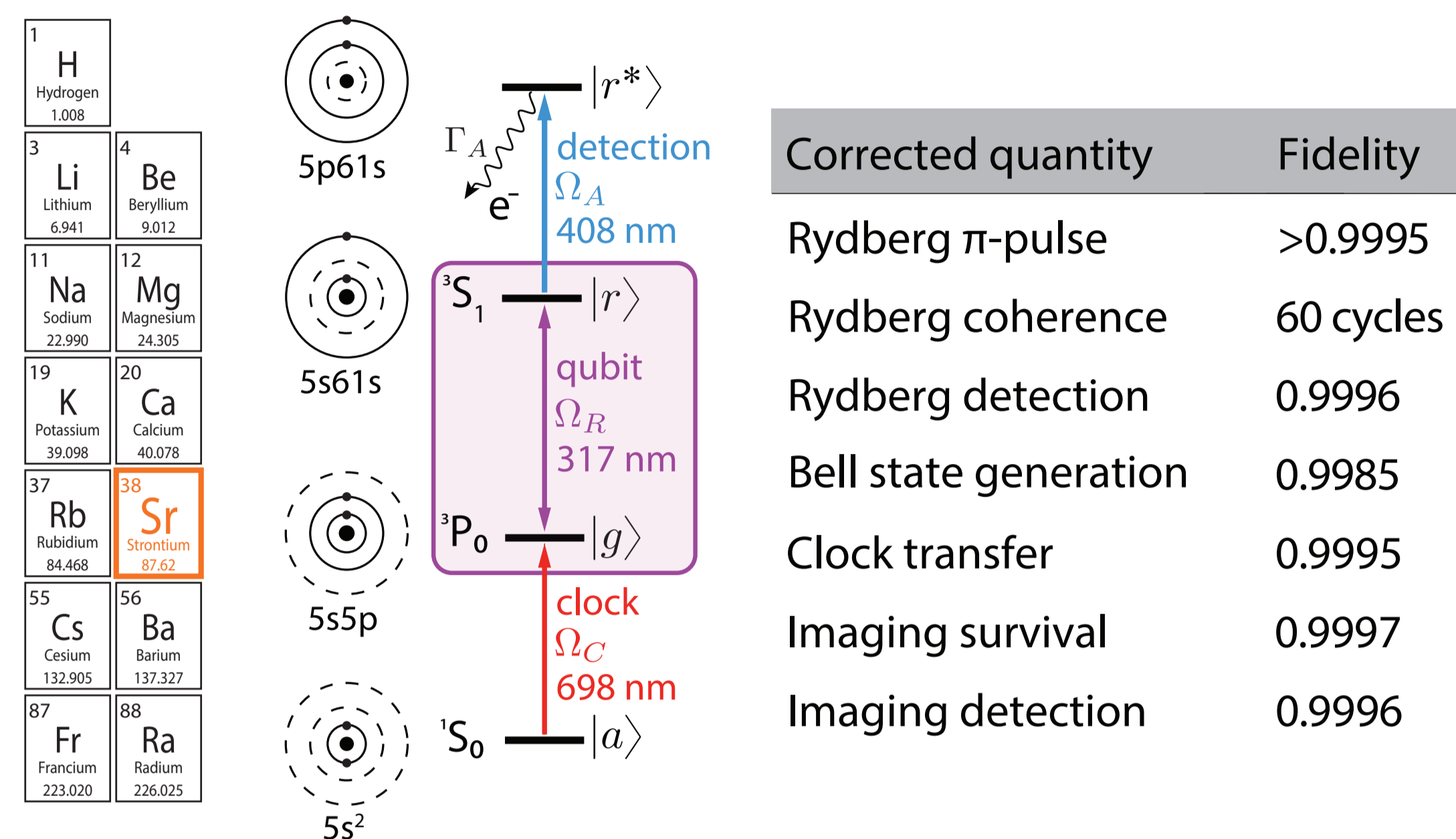


## Strontium Rydberg physics

PRL **130**, 193402 (2023), arXiv:2305.03456 (2023)

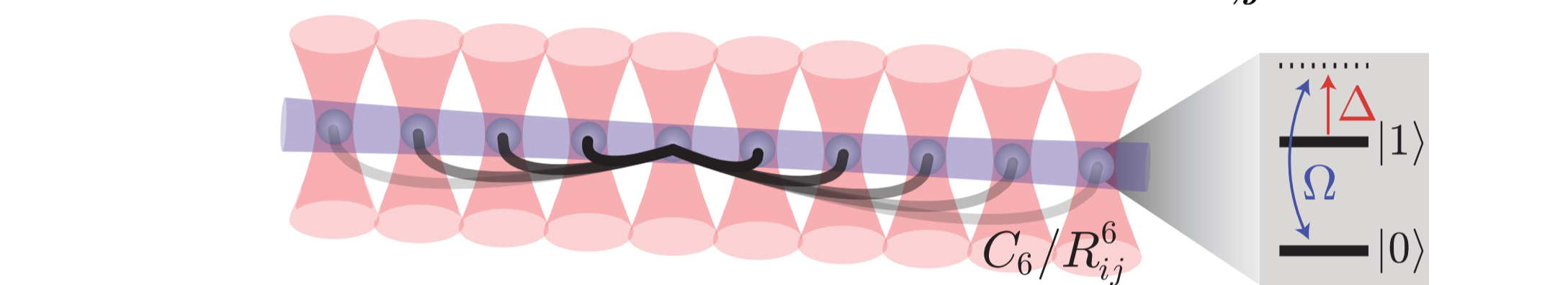
Alkaline-earth element with two valence electrons  
Low-lying optical transitions for imaging and cooling, as well as a metastable "clock" state

High-lying Rydberg state which allows for controllable entanglement generation and many-body simulation

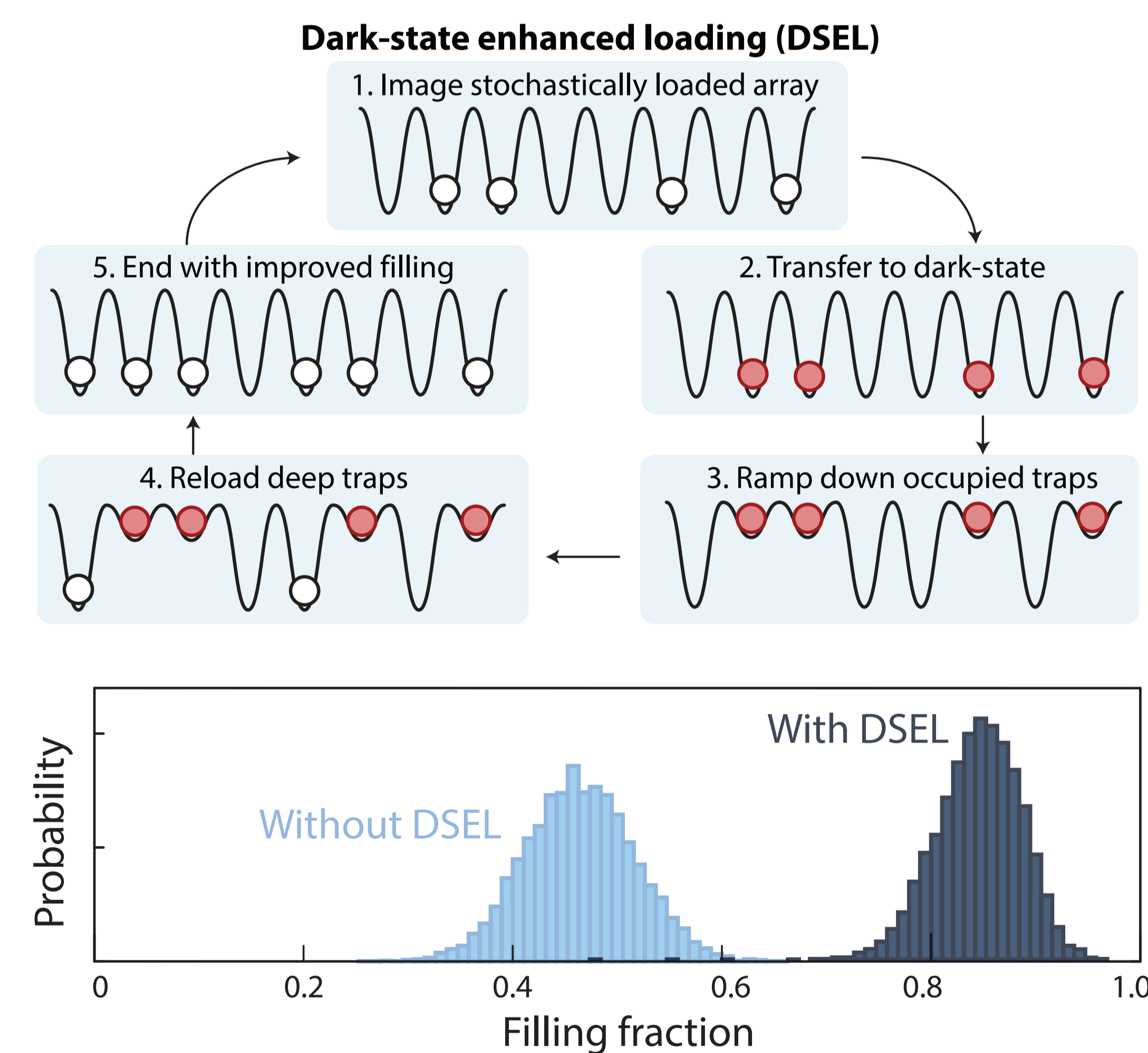


Dynamics are governed by the Rydberg Hamiltonian

$$\hat{H}(\Omega, \Delta, C_6) = \frac{1}{2} \Omega \sum_i \hat{\sigma}_x^i - \Delta \sum_i \hat{n}^i + C_6 \sum_{i,j < i} \frac{1}{R_{ij}^6} \hat{n}^i \hat{n}^j$$



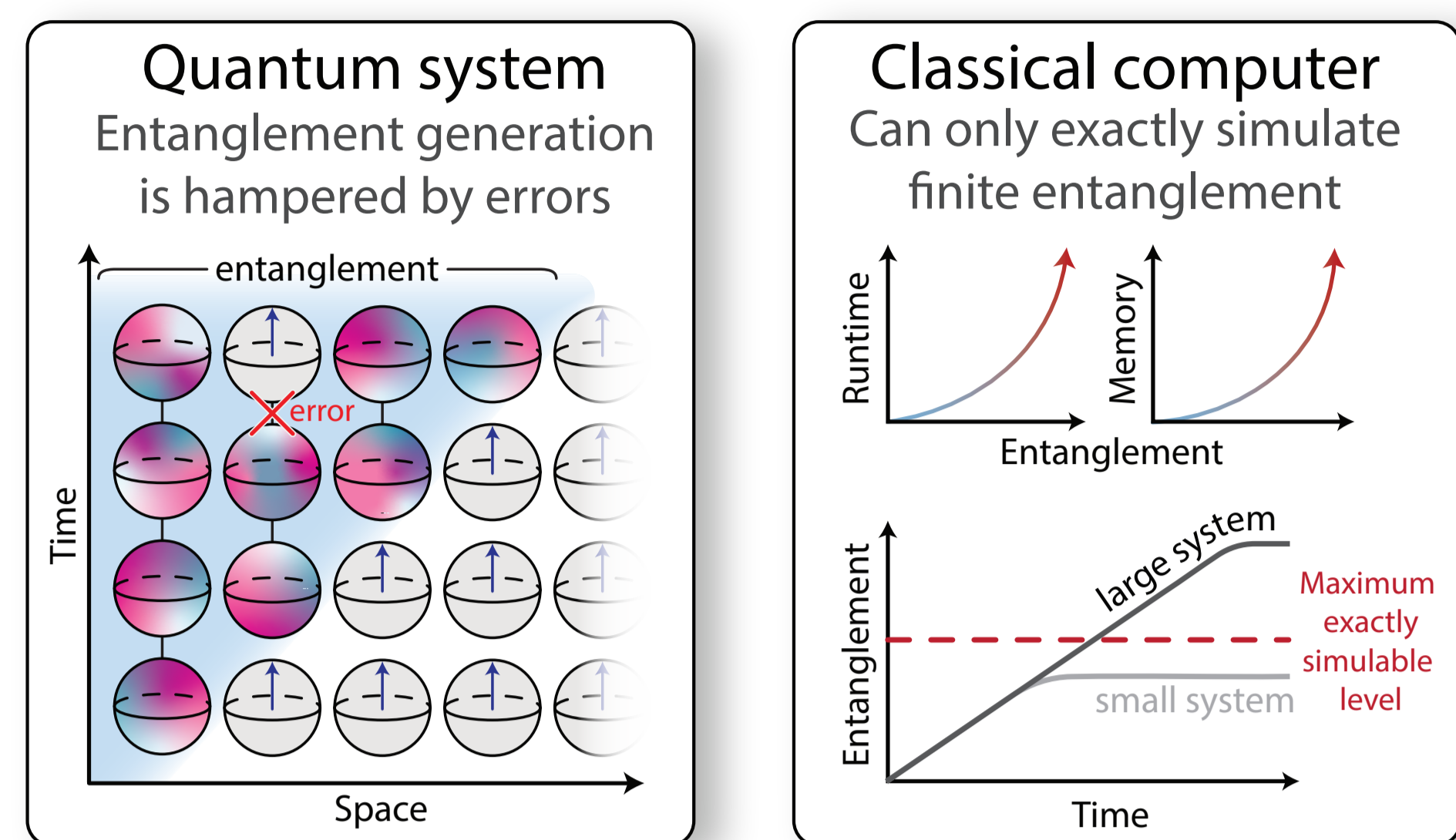
In optical tweezers, the number of atoms per shot is generally limited by the finite stochastic filling (~50%). We overcome this limit with dark-state enhanced loading (DSEL).



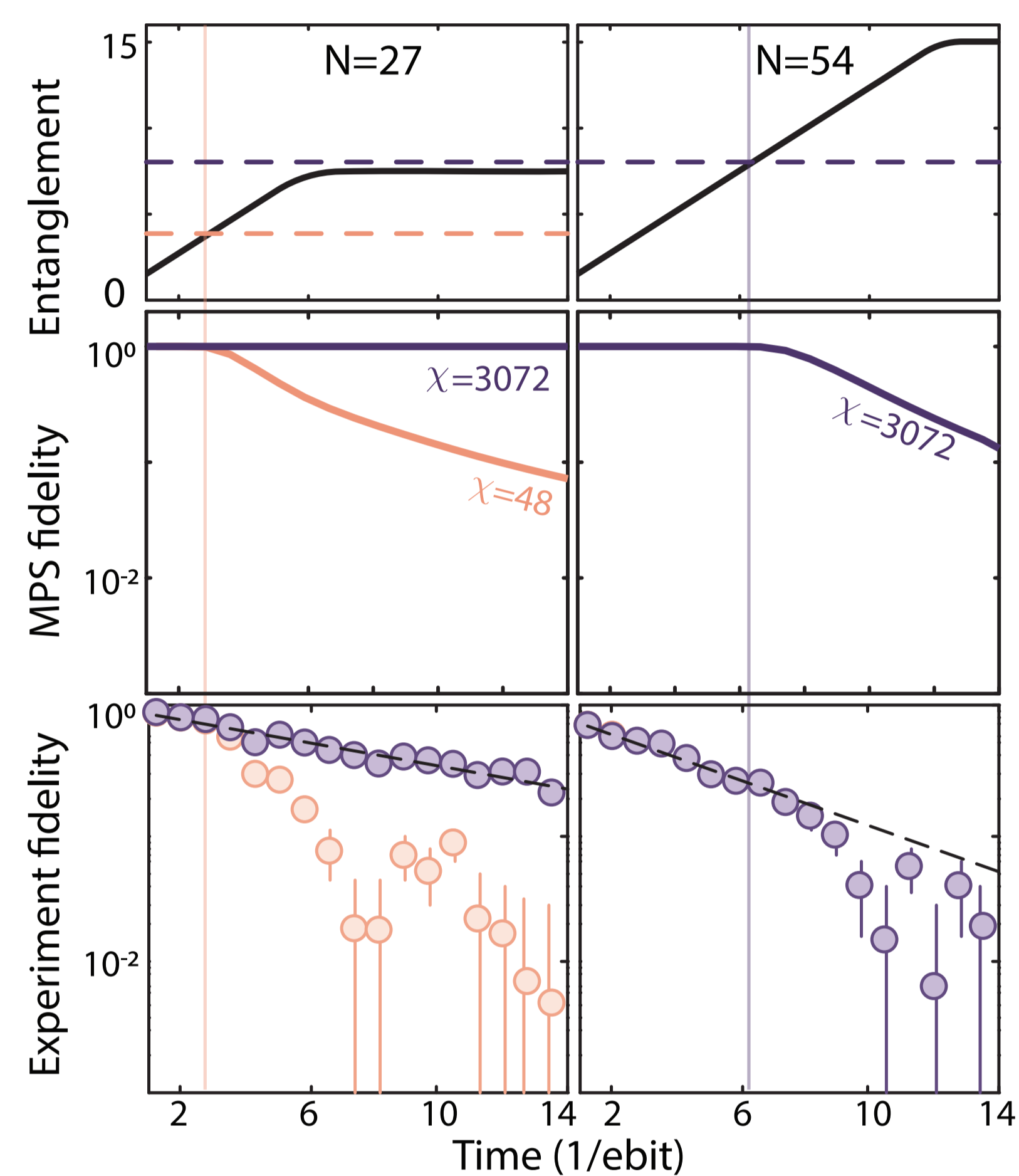
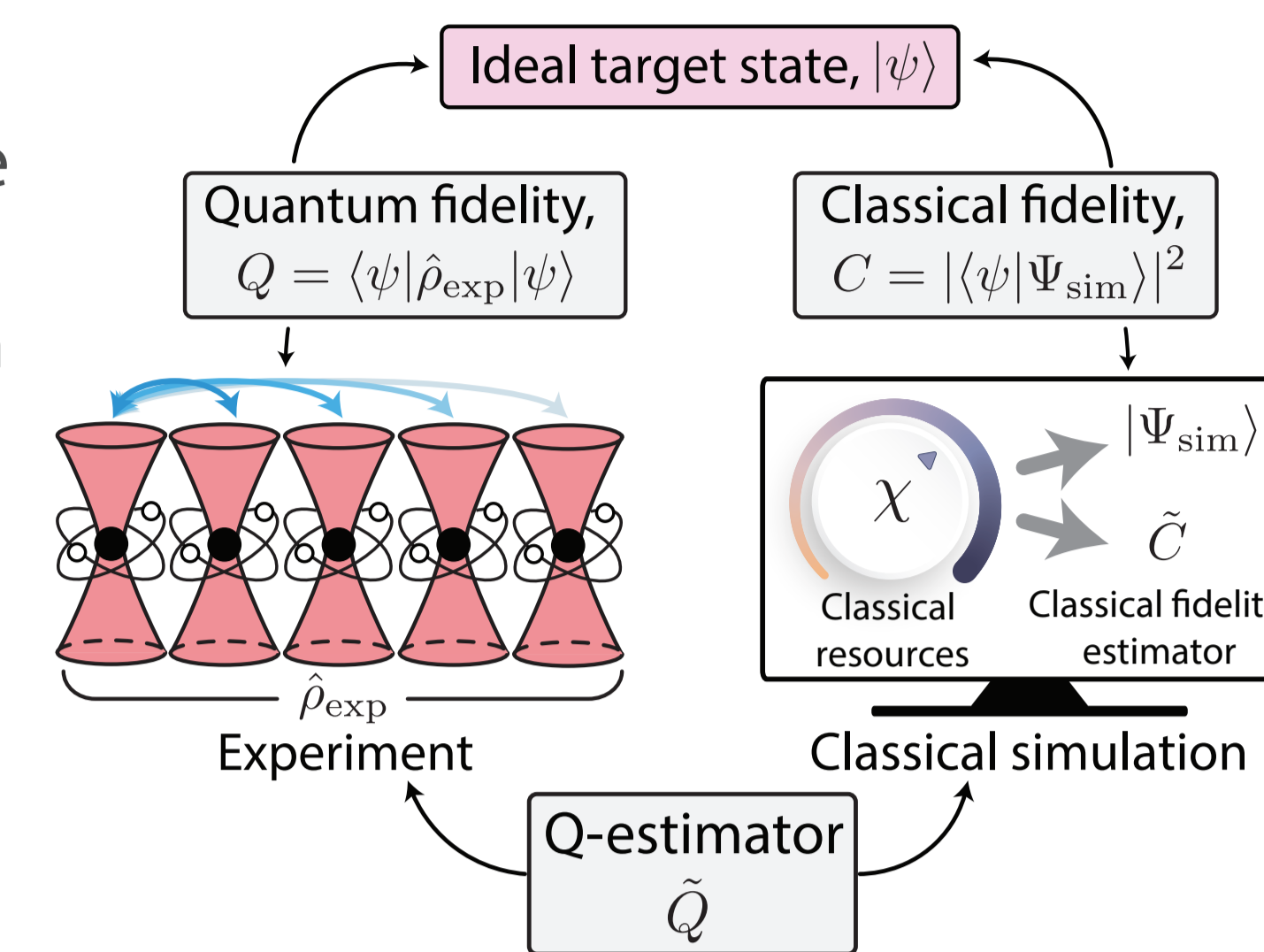
## Quantum simulation at high entanglement

an extension of Nature **613**, 468-473 (2023)

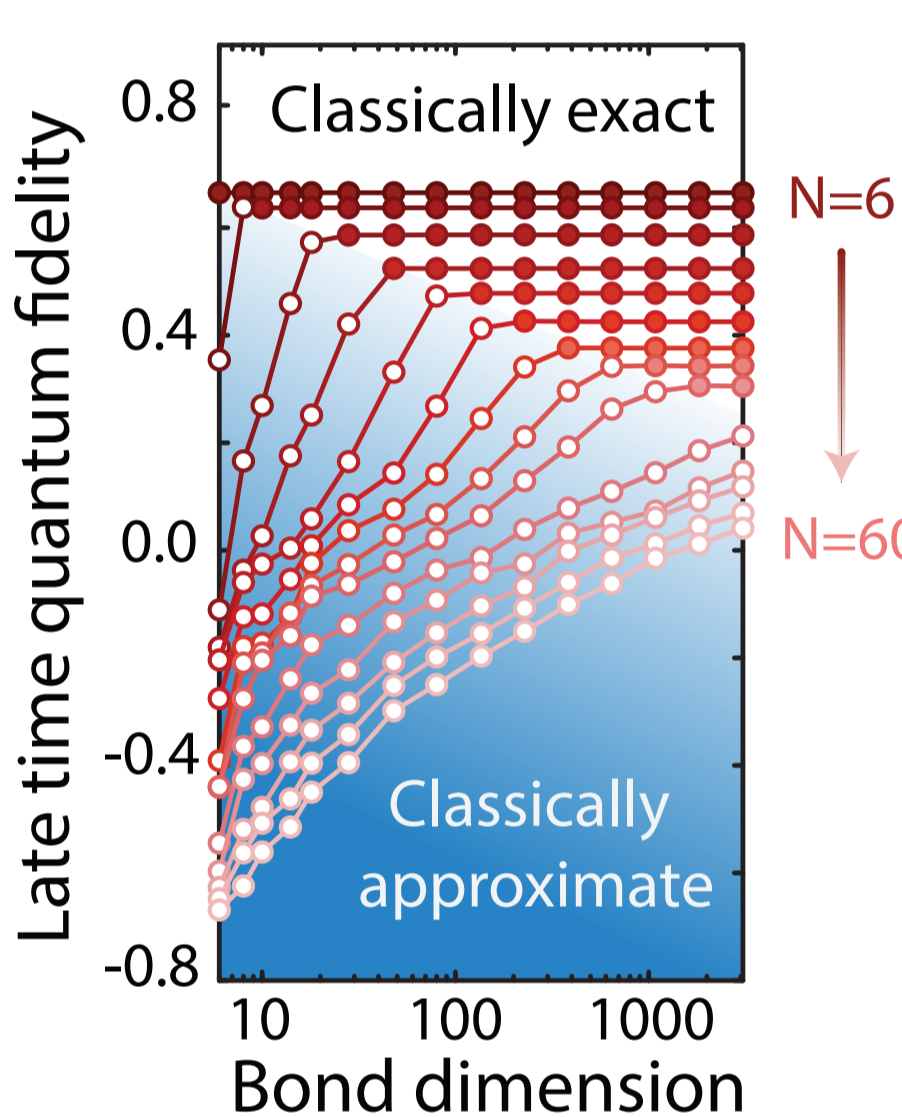
What best represents some ideal quantum dynamics?



We perform high-temperature quenches and benchmark fidelity using cross-correlation with a classical simulation. We can control the bond dimension of the simulation, which limits the maximum simulable entanglement.

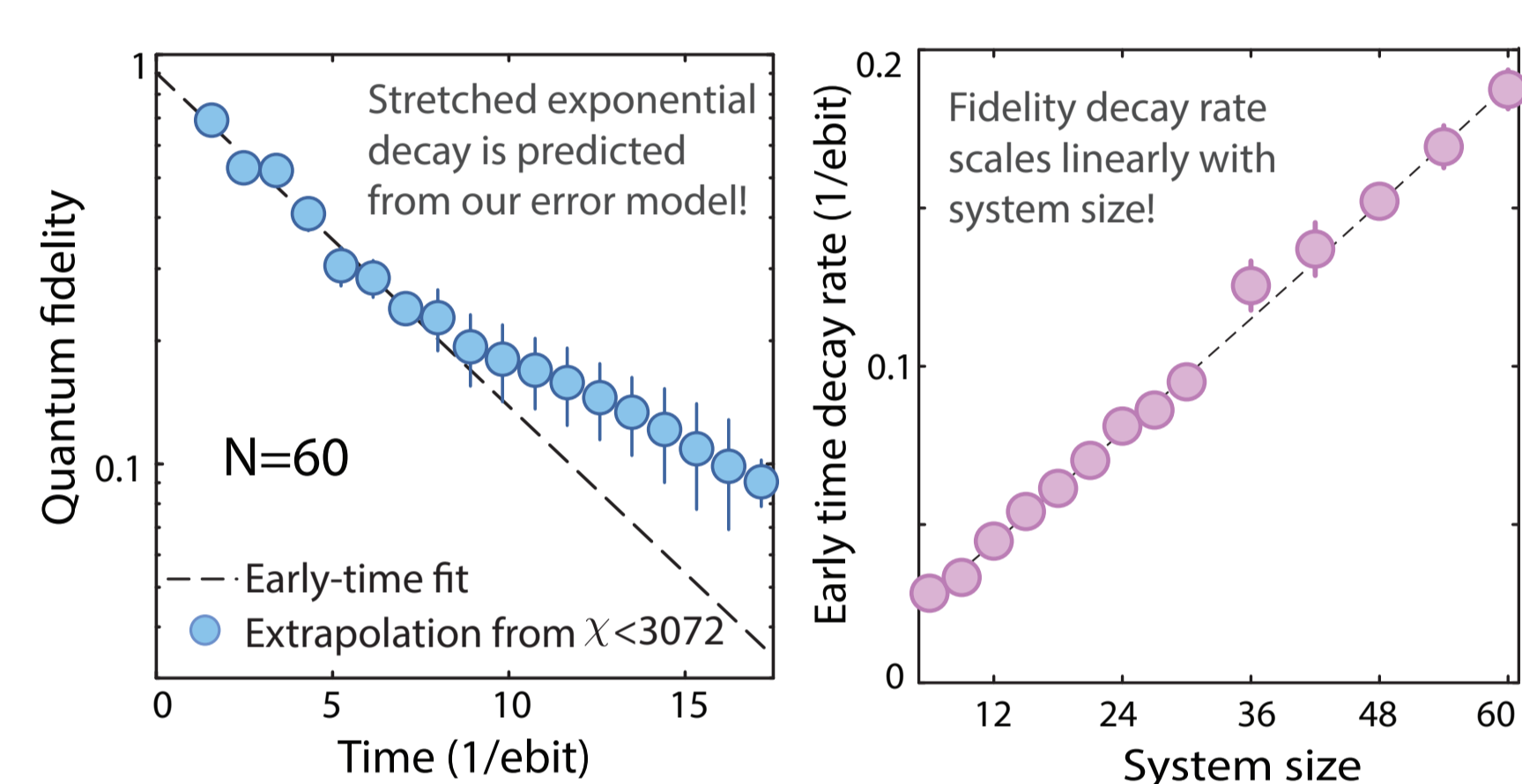


If the bond dimension isn't high enough, the classical computer becomes inaccurate when entanglement is too high, and the benchmarked fidelity drops.

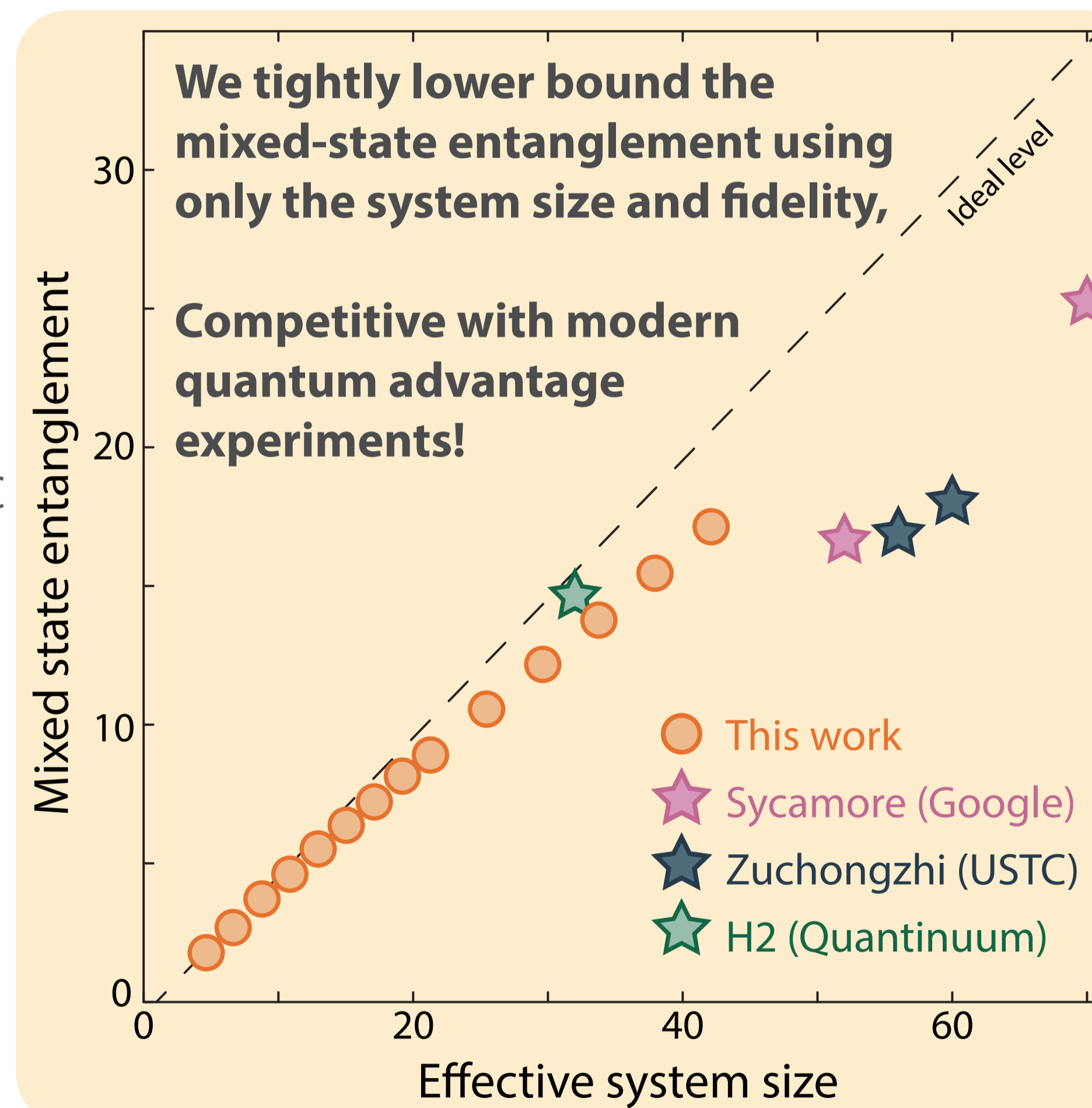
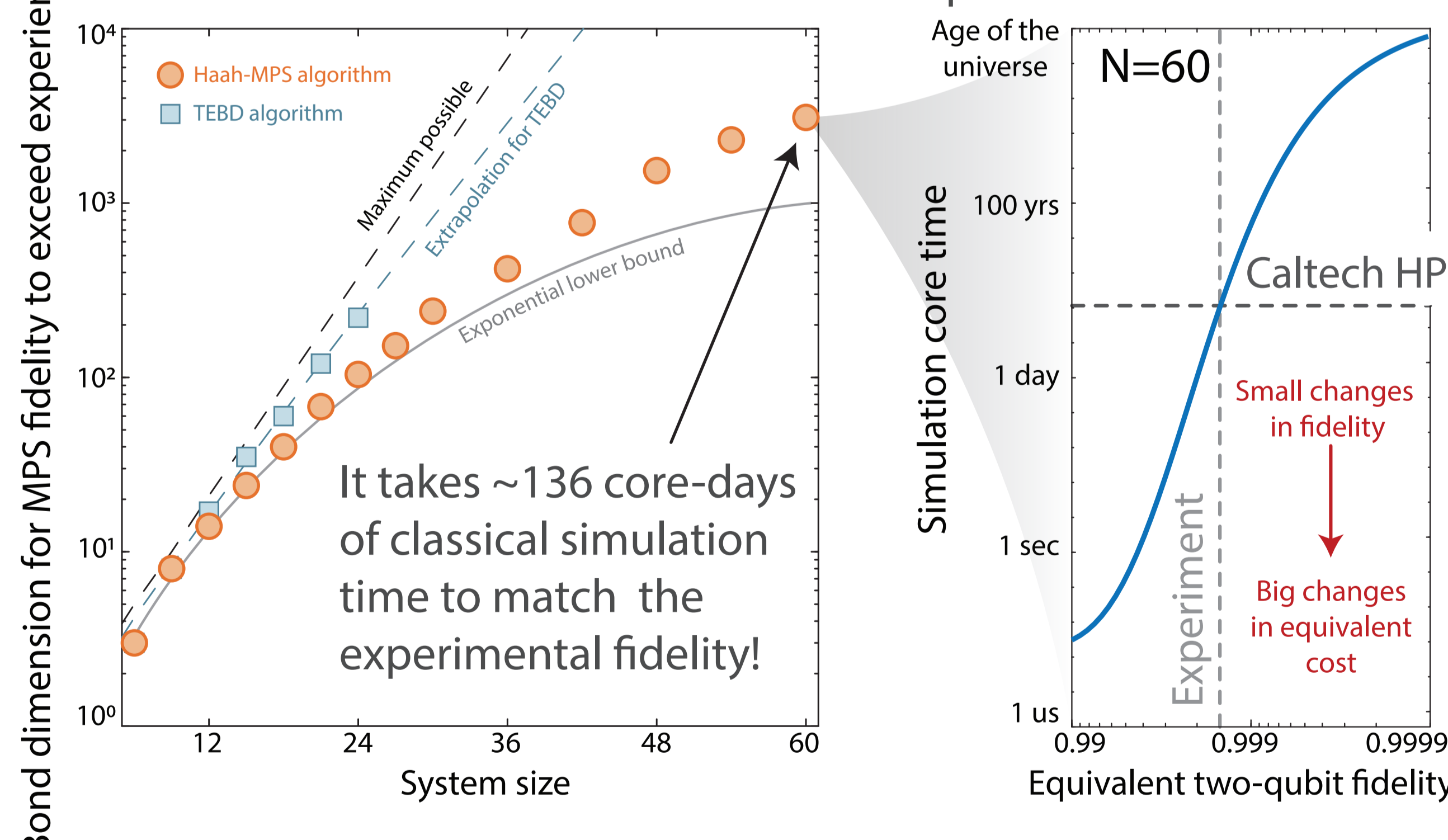


We extrapolate from low entanglement simulations (nearly 90 TB worth!) in order to predict the actual fidelity at large system sizes.

We find 0.091(11) fidelity at N=60 when entanglement saturates, which corresponds to an effective two-qubit fidelity of ~0.999

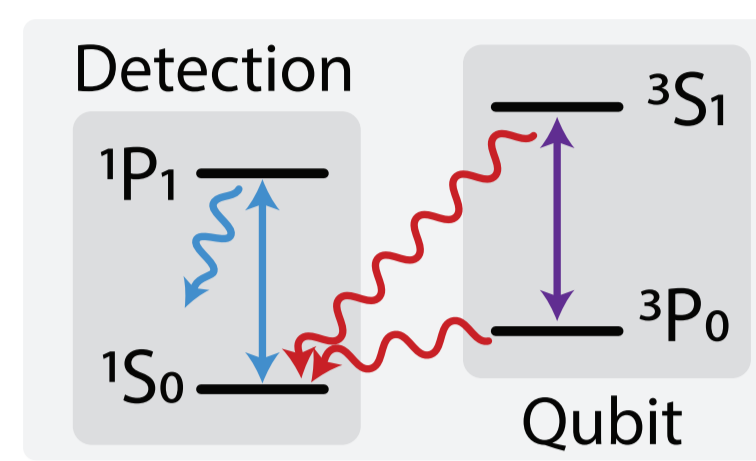
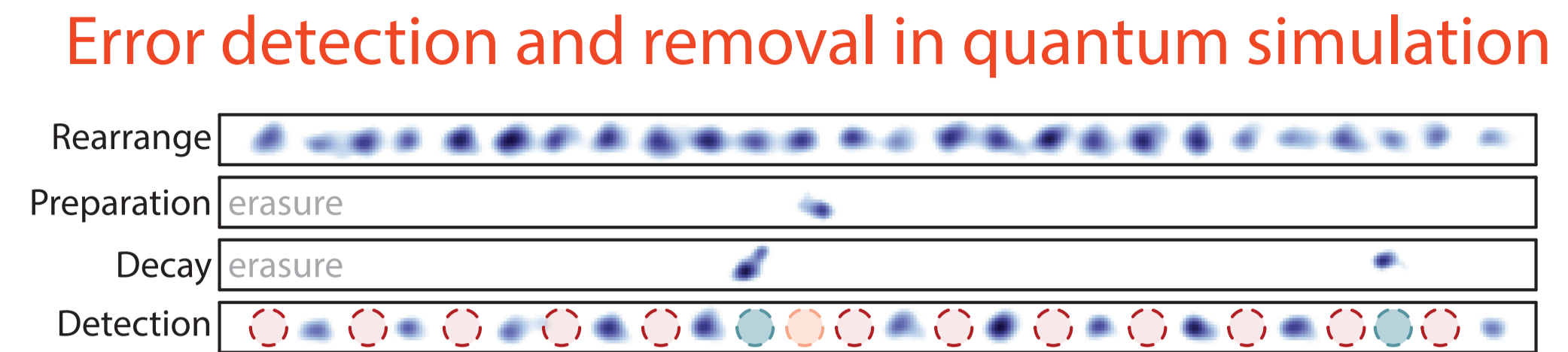


We can define the equivalent cost for a classical computer to reach the same fidelities as our quantum simulator.

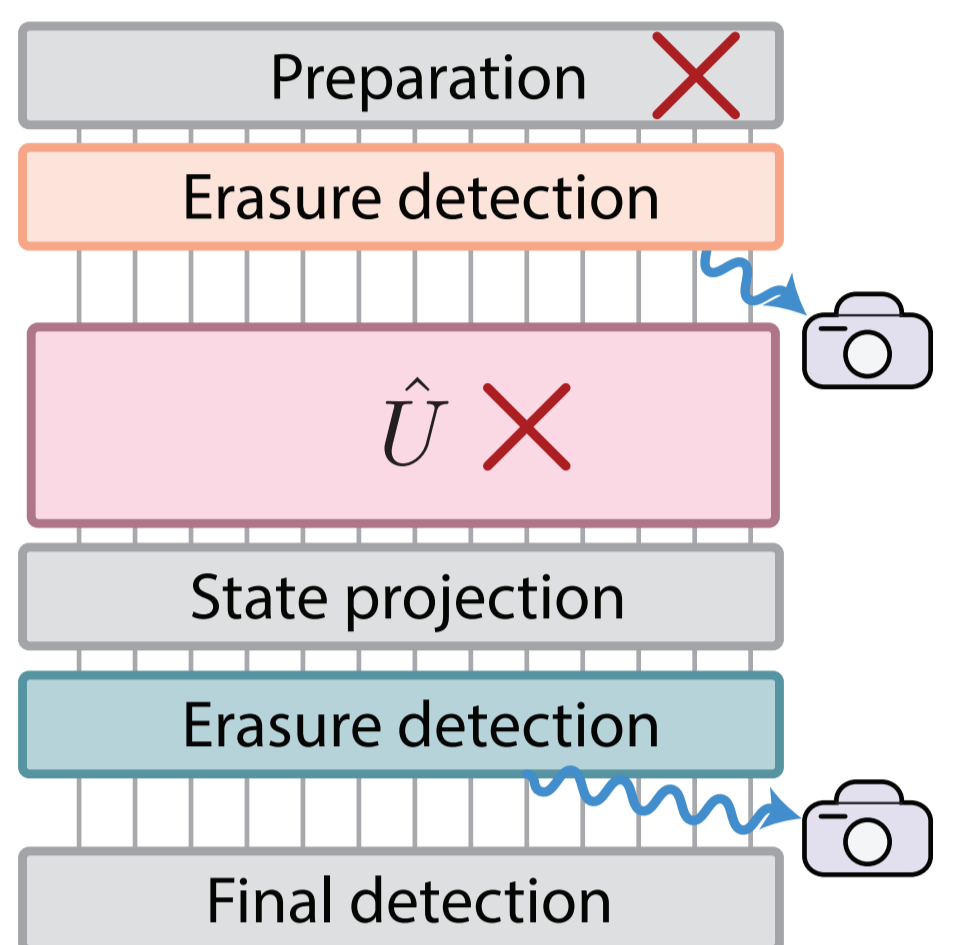


## Erasure conversion

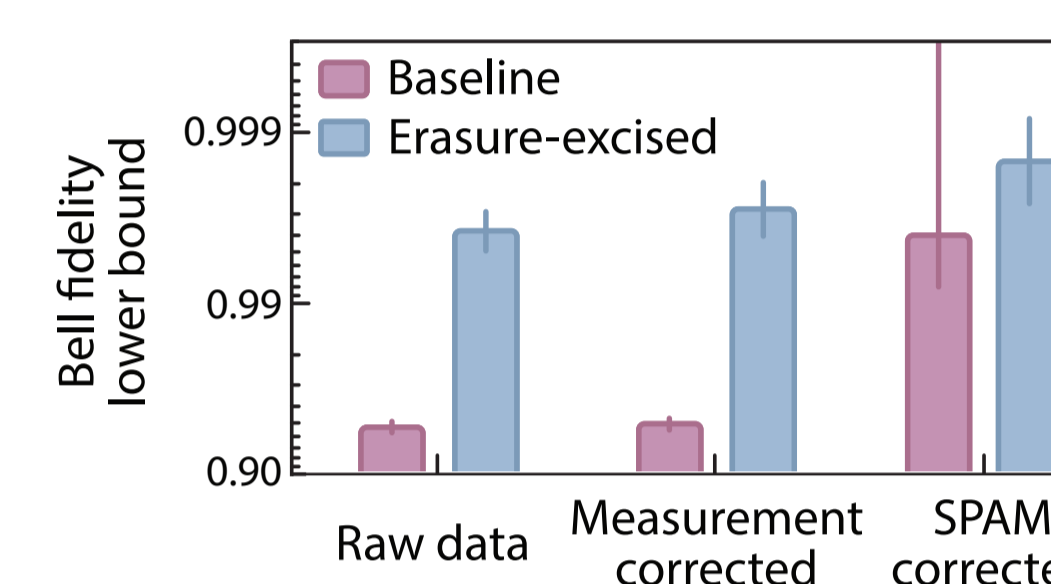
arXiv:2305.03456 (2023)



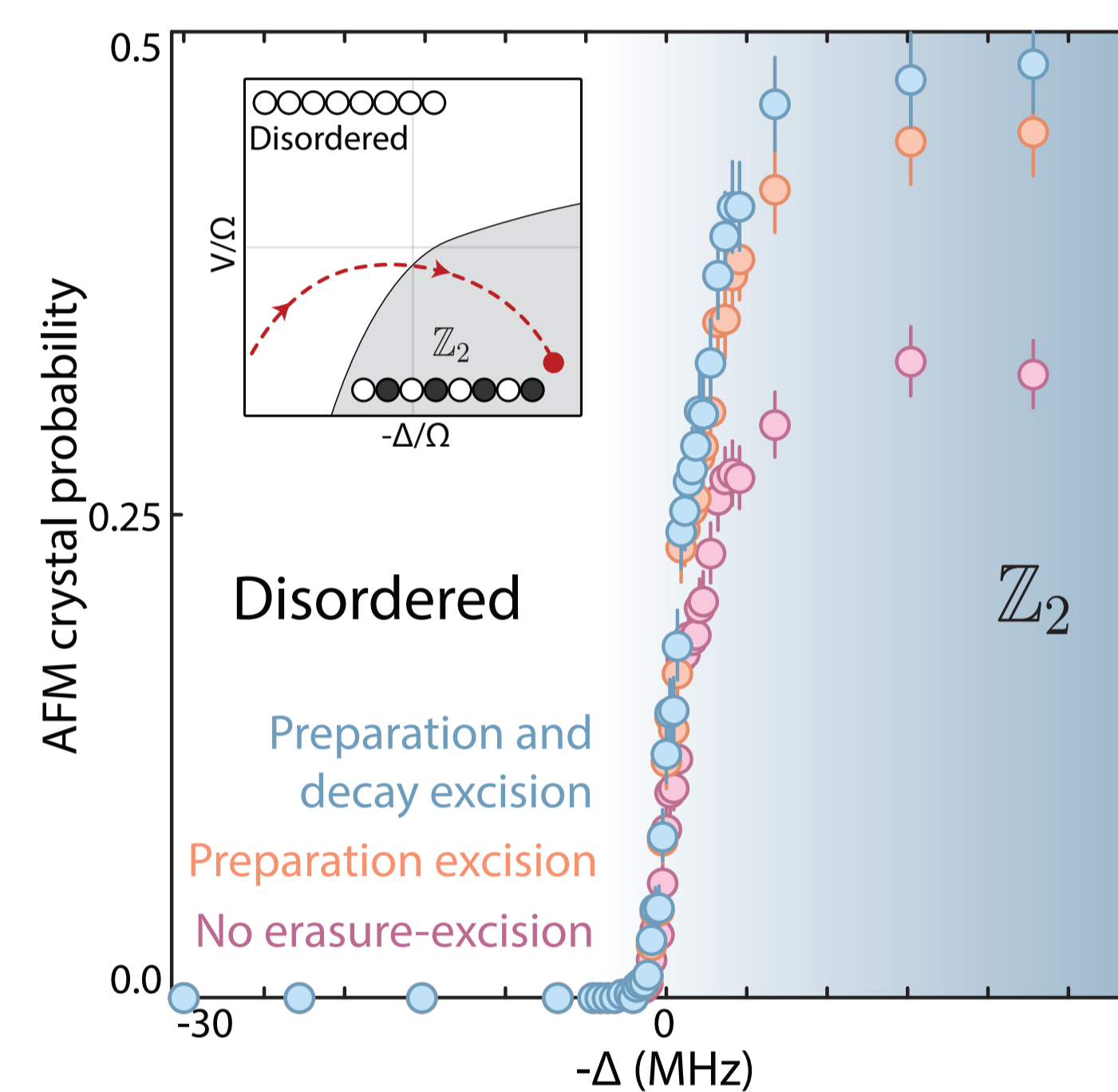
Using fast (10 us) imaging, we can detect preparation and Rydberg decay errors, and can excise these shots with >98% fidelity.



In combination with other improvements, this yields a record 0.9985(9) Bell state generation fidelity

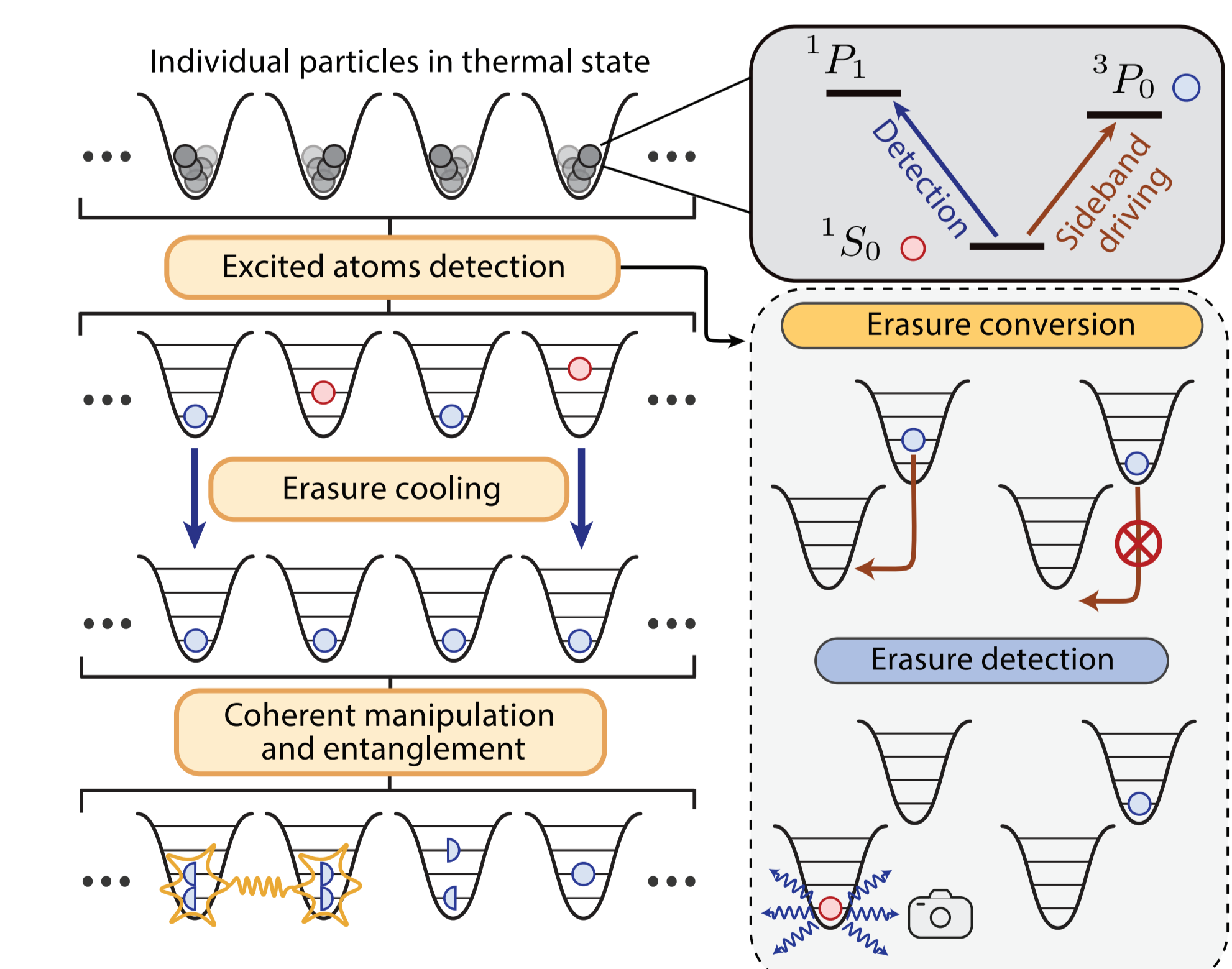


Detecting and distinguishing error sources also leads to noticeable improvements in quantum simulation tasks, like preparing an AFM crystal ground state across a quantum phase transition.

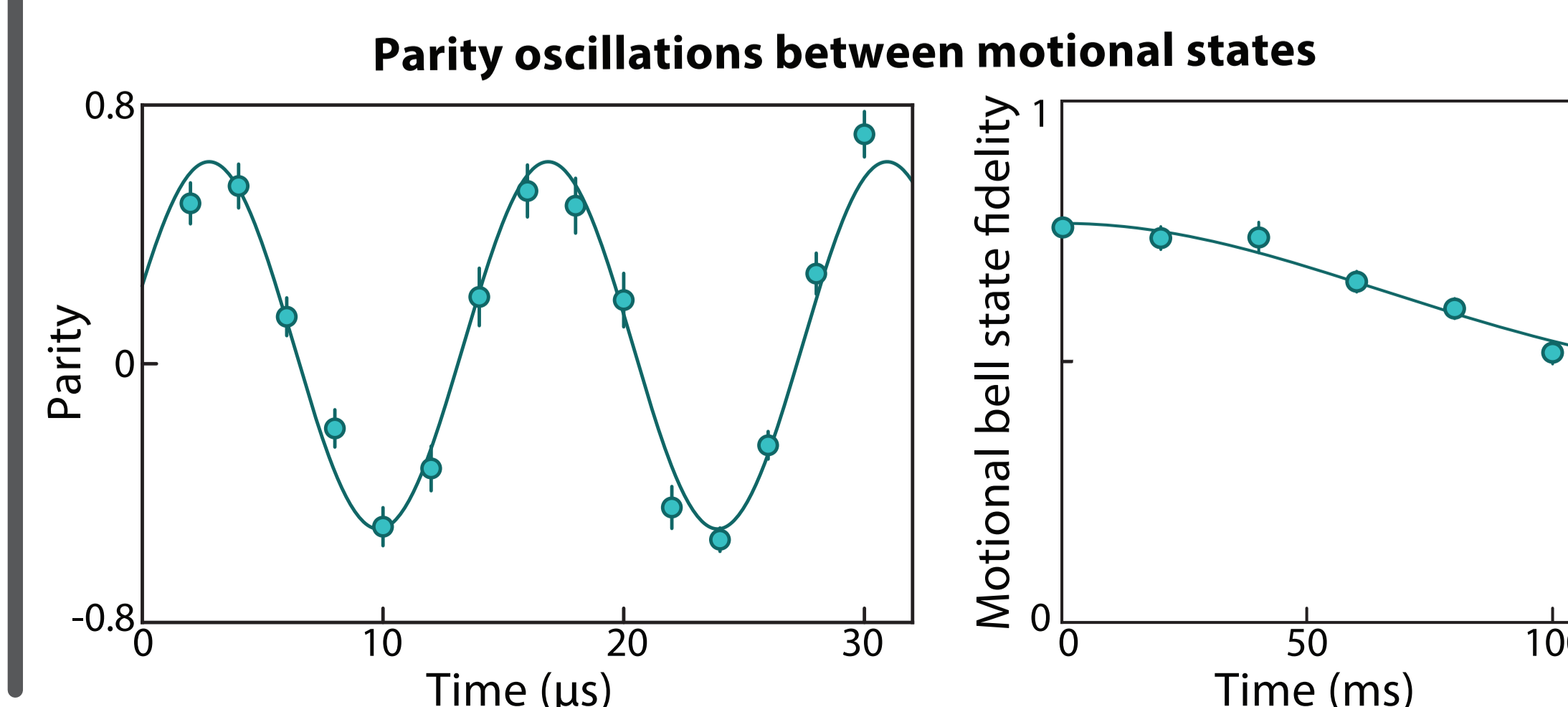


## Coherent motional state control in tweezers

We apply the fast imaging technique to detect atoms in the excited motional state and selectively cool them further.



Motional ground state preparation	0.984
Spin-motion transduction fidelity	0.993
Motional state coherence	>100 ms
Motional Bell-state fidelity (SPAM-corrected)	0.88

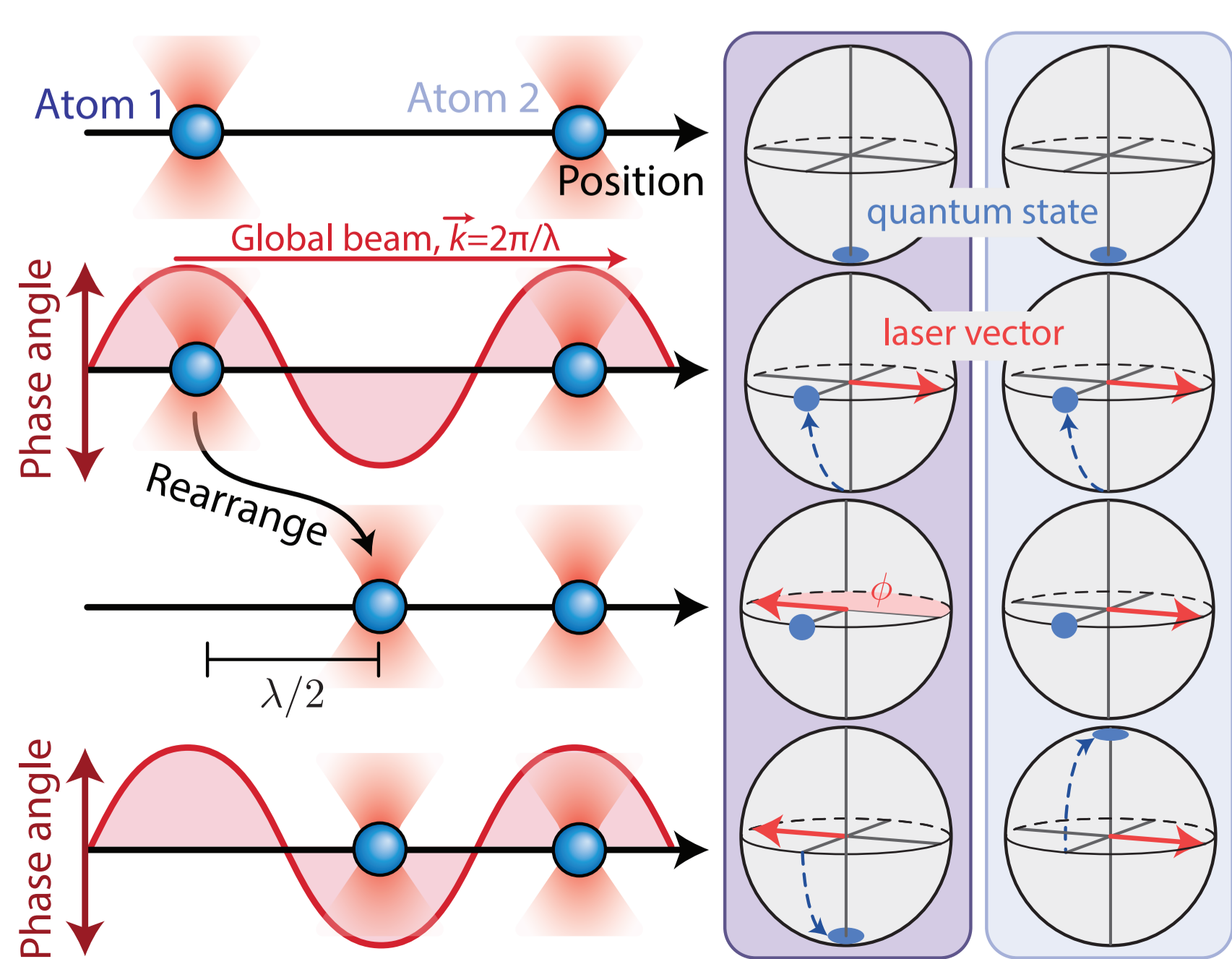


## Arbitrary, parallel, local rotations with atom movements

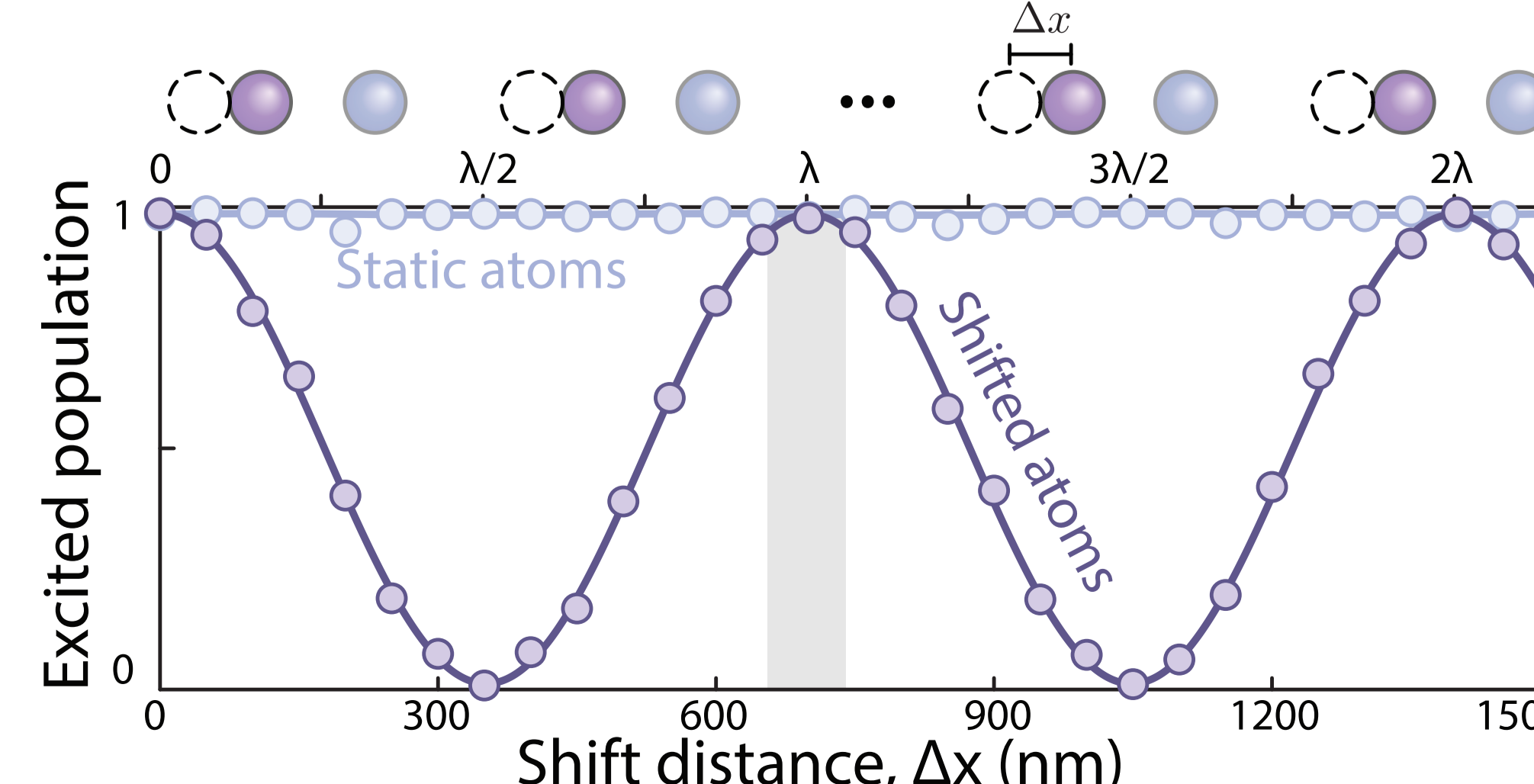
arXiv:2303.16885 (2023)

We achieve single-site addressing with individual motional control across the array of tweezers.

This nanometer-precision movement introduces a phase shift in the atom-laser interaction picture.



This phase shift is realized with fidelity 0.9984(5), resulting in >99% fidelity of performing arbitrary local single-qubit gate in parallel.



This technique enable *in situ*, dual-rail Ramsey interrogation on an optical clock transition, with good (2.5 dB) metrological gains, and the possibility to achieve exponential scaling of the sensitivity with atom number.

