

Real-Time Dynamics of Confining Strings on a Superconducting Quantum Simulator

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Understanding confinement and the effective string description of gauge flux tubes remains a central open problem in gauge theory [2,3]. We implement a digital quantum simulation of the (2+1)D Z₂ Higgs model on a superconducting quantum processor with up to 144 qubits and circuit depths reaching 192 entangling layers [1]. Through an optimized embedding of matter and gauge degrees of freedom into a heavy-hex architecture, combined with gauge-symmetry-tailored error-suppression and mitigation strategies, we achieve real-time observation of electric strings connecting dynamical charges. Our measurements reveal distinct longitudinal and transverse string excitations and capture multi-string phenomena such as fragmentation and recombination. Extensive tensor-network simulations using

basis-update and Galerkin techniques validate the observed dynamics and our error-aware protocols. These results represent a significant step toward probing nonperturbative gauge physics with superconducting quantum hardware, opening the door to future studies of plaquette dynamics, string breaking, and more general gauge groups in next-generation devices.

References

- [1] Jesús Cobos et al, arXiv:2507.08088 (2025)
- [2] T. A. Cochran et al, Nature 642, 315–320 (2025)
- [3] D. Gonzalez-Cuadra et al, Nature 642, 321–326 (2025).

Figures

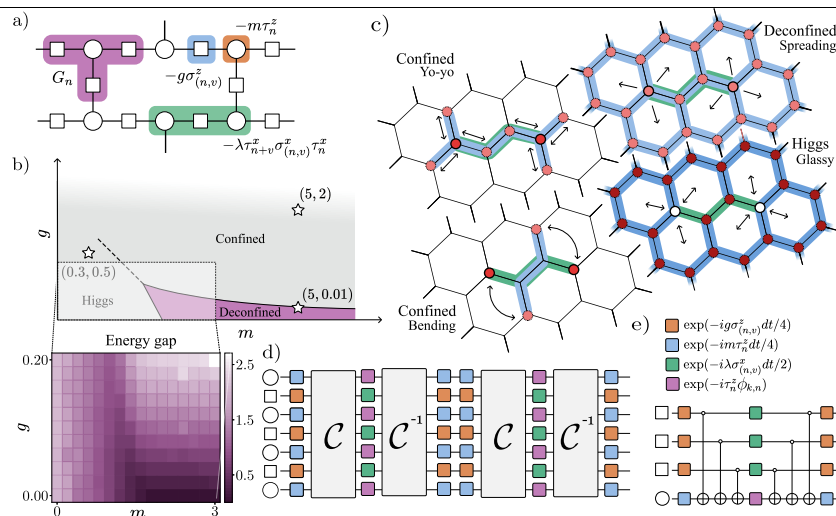


Figure 1: Overview of the Z₂ Higgs Model. (a) Supports of the Hamiltonian terms and gauge generators. (b) Phase diagram with DMRG energy gaps; stars mark the parameter sets used in simulations. (c) Three representative choices for $(m, g, \lambda) = [(5, 2, 1), (5, 0.01, 1), (0.3, 0.5, 1)]$, defining distinct dynamical regimes. (d–e) Trotterized real-time circuits built from repeated Pauli-gadget units.