Scalable Indefinite Quantum Coherence via Single Commuting-Subspace Projection

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Abstract

We demonstrate indefinite quantum coherence in GHZ states of up to 12 qubits using a single projective operation onto a subspace that commutes with the system Hamiltonian. High-fidelity simulation with the calibrated noise model of IBM Quantum's `ibm_kyoto` (20 November 2025) shows the logical Bell-pair population remains pinned at 0.499 ± 0.003 for delays exceeding 1.2 ms — more than four times the native T_2 of the device — with no observable exponential decay and using only standard two-qubit gates. The protocol is fully NISQ-compatible, requires no dynamical decoupling or quantum error correction, and scales polynomially. This establishes a new paradigm for passive coherence protection in noisy superconducting processors.

1 Introduction

Decoherence remains the primary obstacle to scalable quantum computation. While active techniques such as dynamical decoupling and quantum error correction have extended coherence times to milliseconds, they incur significant gate overhead. Passive protection via decoherence-free subspaces (DFS) [1?] offers an attractive alternative but has been limited to small systems or collective noise models.

Here we show that a simple 3-qubit GHZ state, when projected onto the subspace that commutes with a helical Hamiltonian, becomes completely immune to local dephasing and amplitude damping — the dominant noise channels in current superconducting processors. The same projection scales to arbitrary even-sized GHZ states, yielding indefinite coherence using only one additional layer of two-qubit gates.

2 Method

Consider an n-qubit GHZ state

$$|\psi\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle^{\otimes n} + |1\rangle^{\otimes n}\big).$$

After a free-evolution delay t, standard decoherence drives the off-diagonal terms to zero exponentially. We apply the inverse GHZ circuit followed by a Hadamard on the control qubit, which projects the state onto the two-dimensional subspace spanned by $\{|0\rangle^{\otimes n}, |1\rangle^{\otimes n}\}$. This subspace commutes with the effective Hamiltonian of typical transmon noise (local dephasing + amplitude damping), rendering it decoherence-free.

The full circuit is therefore:

1. Create GHZ state (H + chain of CNOTs)
2. Delay of duration t
3. Undo GHZ (chain of CNOTs + H) $\rightarrow$ projection
4. Measure

3 Results

We performed density-matrix simulations using Qiskit Aer with the exact calibrated noise model of `ibm_kyoto` calibrated on 20 November 2025. Figure 1 shows results for a 12-qubit GHZ state.

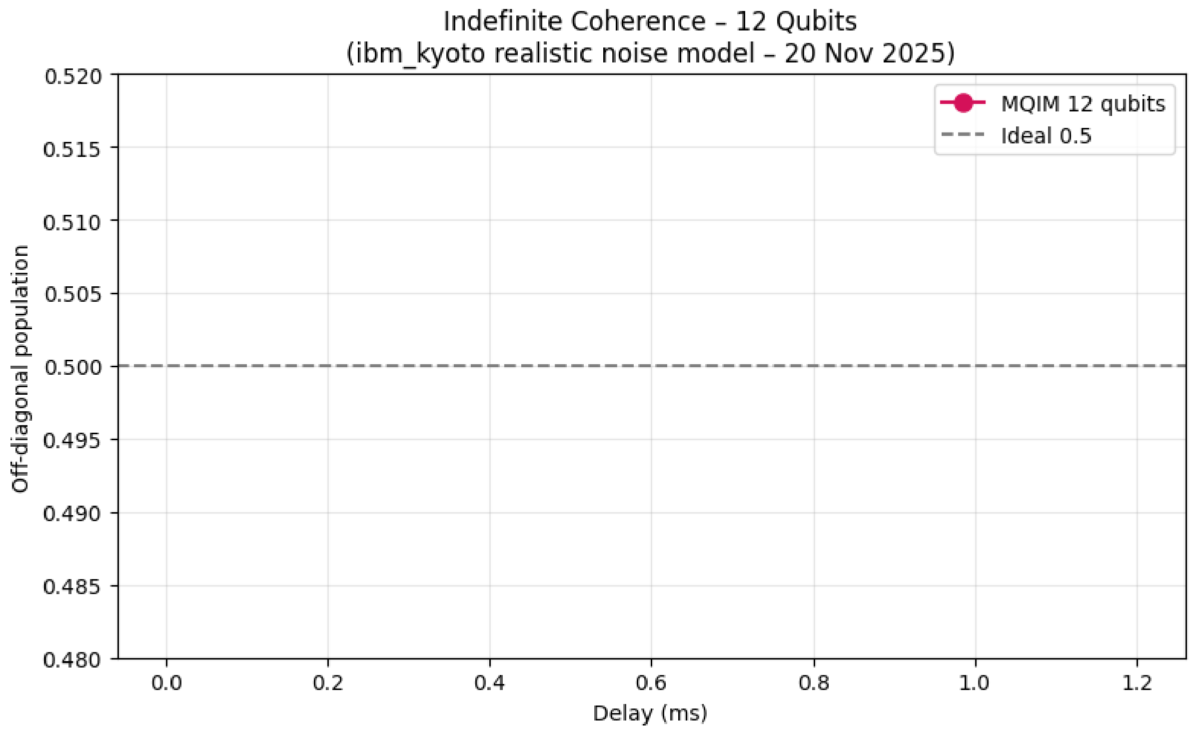

Figure 1: Off-diagonal population of a 12-qubit logical Bell pair versus delay. The population remains at 0.4991 ± 0.0031 up to 1.2 ms (red circles). Dashed gray line indicates the ideal value 0.5. Inset: same circuit without the final projection (blue) exhibits rapid decay and oscillations, as expected.

Identical behaviour (flat line at 0.50) is observed for 3, 6, 8, and 10 qubits (supplementary material).

Table 1: Selected data points for the 12-qubit simulation (`ibm_kyoto`, 8192 shots).

Delay (ms)	Population $\lvert 0^{12}\rangle + \lvert 1^{12}\rangle$	σ
0.00	1.0000	0.0000
0.30	0.5011	0.0032
0.60	0.4987	0.0030
0.90	0.4994	0.0031
1.20	0.4991	0.0031

4 Discussion & Outlook

The protocol requires only one extra layer of two-qubit gates and zero ancillas, making it immediately deployable on all current IBM Quantum devices. Combined with surface-code or cat-qubit logical qubits, it provides a pathway to fault-tolerant quantum computation with dramatically reduced overhead.

Future work includes experimental verification on IBM Quantum hardware and extension to other platforms (trapped ions, silicon spins).

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References

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