Tools for Quantum Algorithms, Protocols, Benchmarking, Architectural Design and Co-Design

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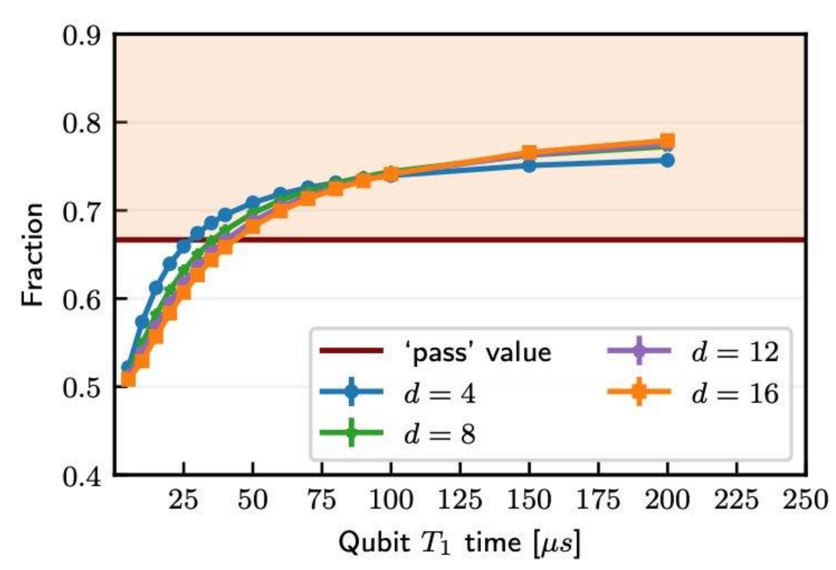
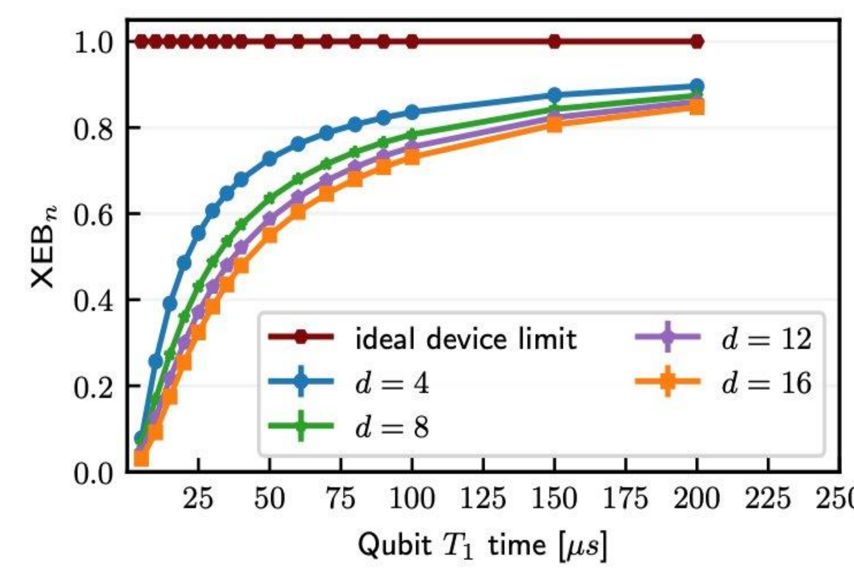
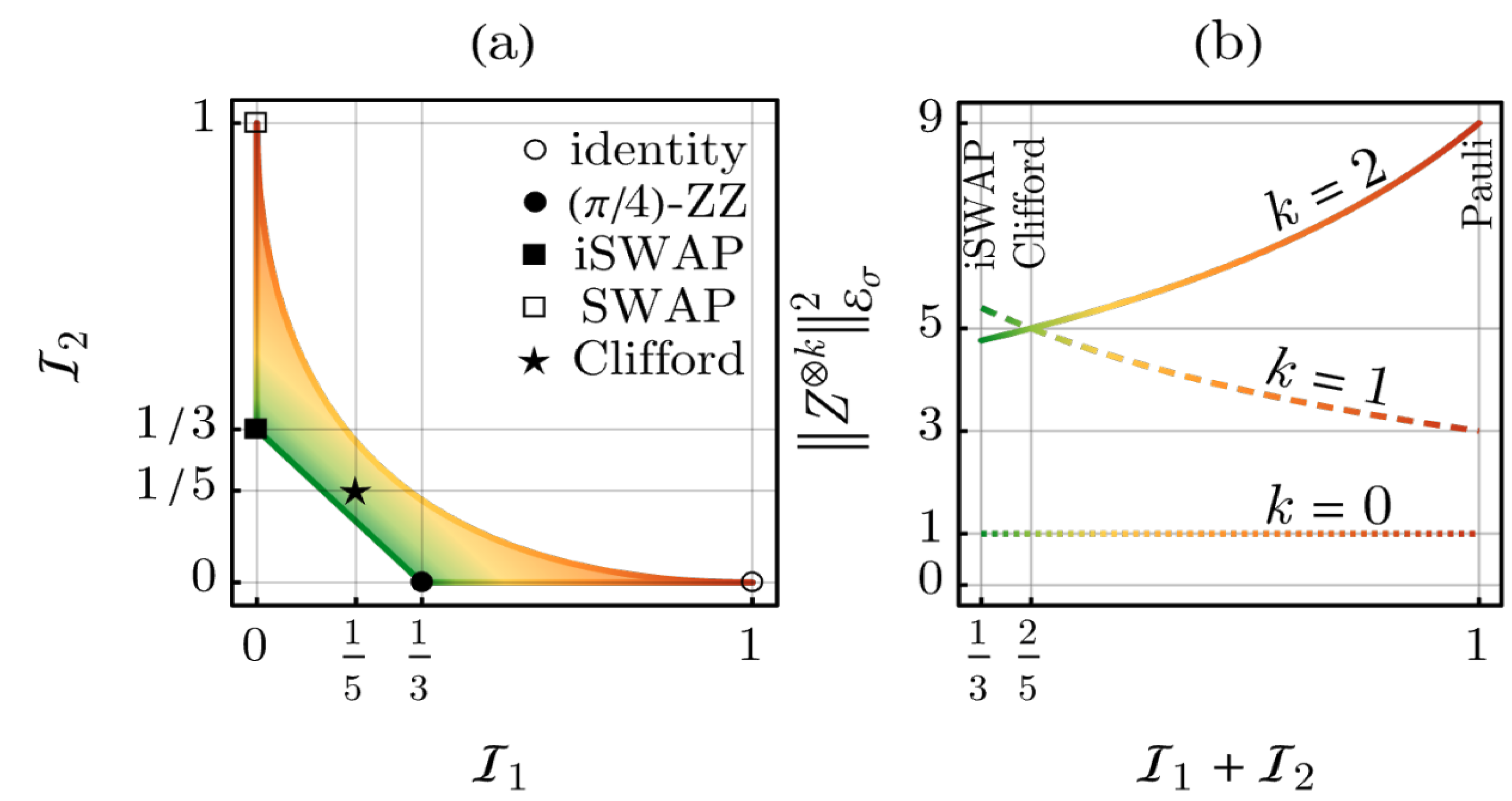
Benchmarking SQMS devices

Sampling tests and tomographic protocols to assess the performance of qubit and qudit devices.





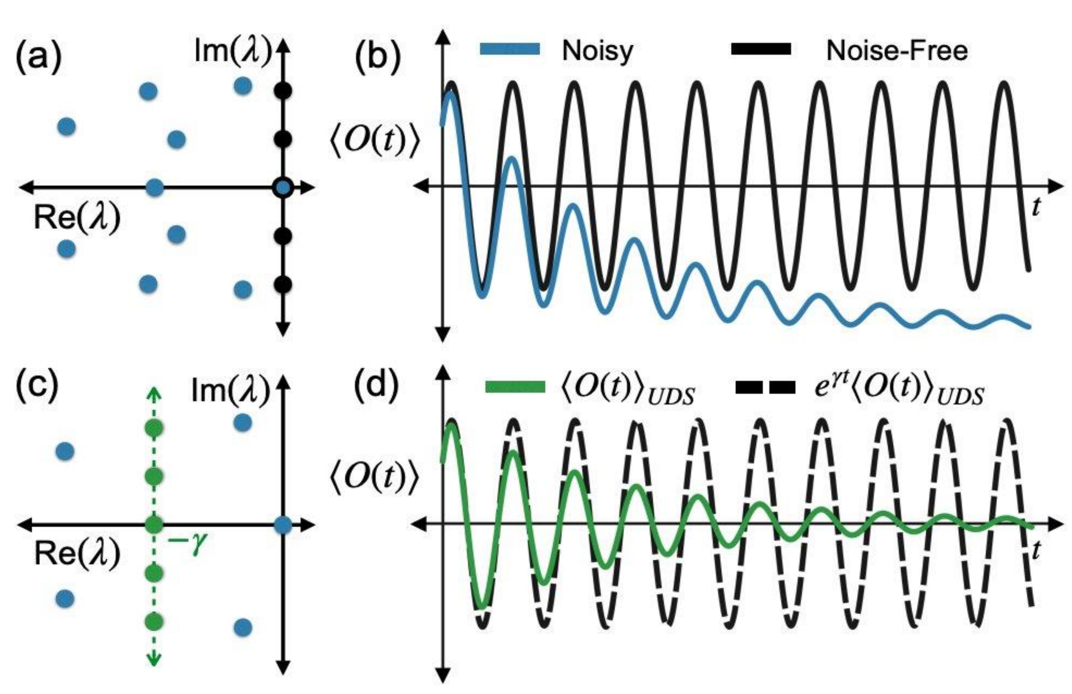
Results of Heavy Output Generation (HOG) test and Cross-Entropy Benchmark (XEB) on cavity qudit coupled to transmon qubit. Heavy bitstring fraction for various qudit dimensions (left) and XEB scores (right) as a function of qubit T1 time. [1]

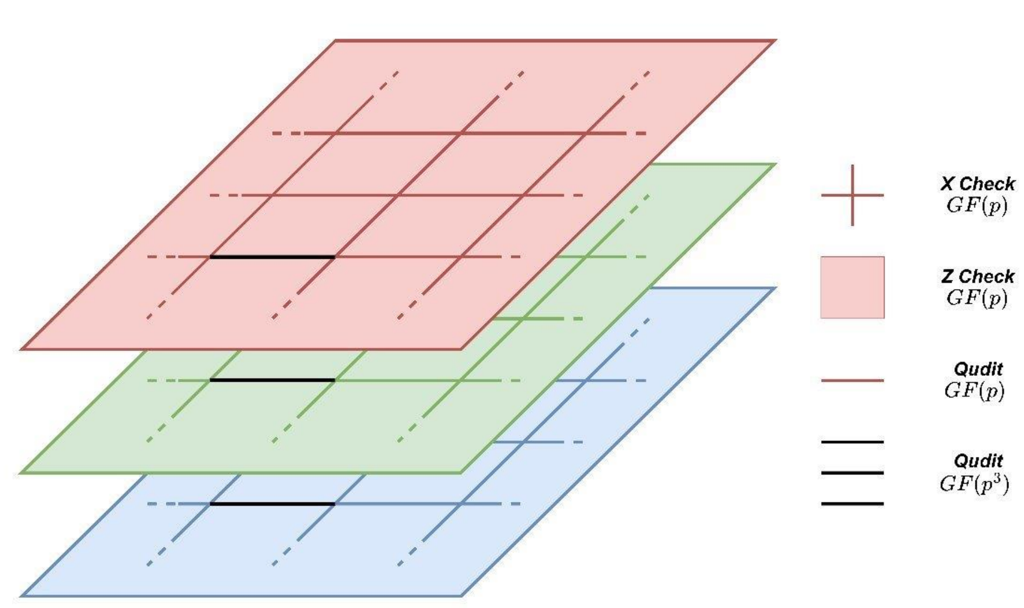


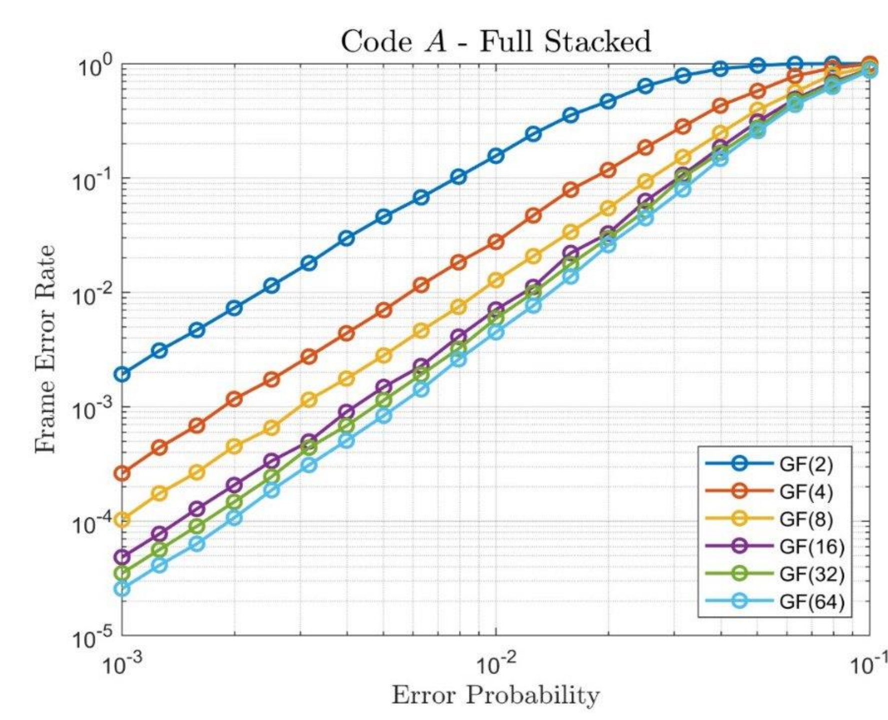
Feasible domain (left) and the corresponding shadow norm (right), and therefore sample complexity, of various dual-unitary brick-wall circuits. [2]

Quantum Error Mitigation and Correction

Toward reliable SQMS quantum processing.





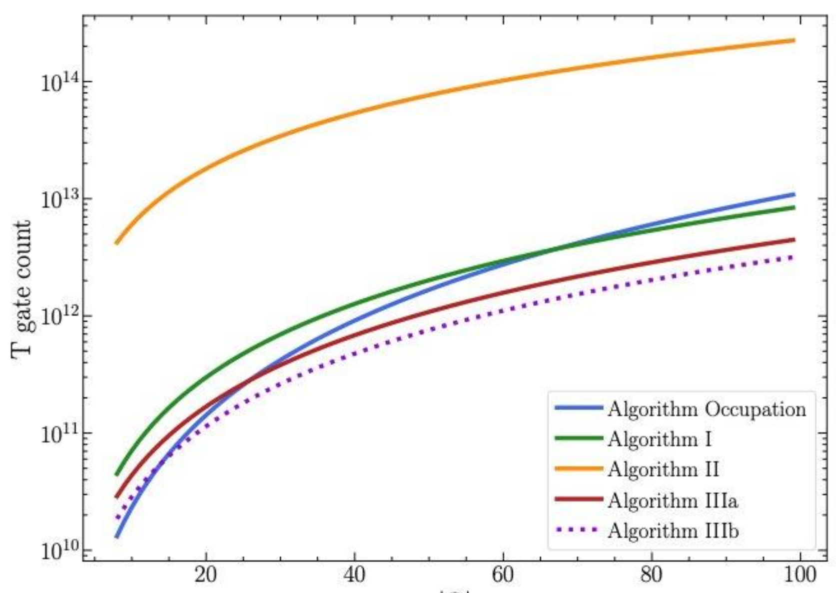


Eigenvalue distribution of Liouville operator for generic (a) and uniformly decaying subspaces (b). Operator expectation values for the former (c) and latter (d). [3]

Qudit toric code over GF(8) for an 8-dim qudit visualized as a stack of 3 layers of the qubit toric code over GF(2) (left). Frame error rate as a function of error probability for the stacked hypergraph product code (right). [4]

Resource Estimates for Quantum Algorithms for High-Energy Physics (HEP)

What it will take to realize quantum advantage over classical computers for these applications.



Algorithm	Qubit #	T gate #
Occ. Trotter	$O\left(N\|\Omega\| + \log\left(\frac{\lambda N}{M\epsilon_E}\right)\right)$	$O\left(\frac{\lambda N^7 \|\Omega\|^3}{M^{5/2}\epsilon_E^{3/2}} \log\left(\lambda \frac{N\|\Omega\|}{M\epsilon_E}\right)\right)$
Amp. Trotter	$O\left(\|\Omega\| \log(k) + \log_2\left(\frac{\|\Omega\|\Lambda k\left(\Lambda k + M^2\right)}{\epsilon_E}\right)\right)$	$\tilde{O}\left(\frac{\|\Omega\|^{3/2}\sqrt{\Lambda^2 k^5 + \Lambda M^2 k^4} \log^4(k)}{\epsilon_E^{3/2}}\right)$
Amp. Qubitized I	$O\left(\|\Omega\| \log k + \log^2 k + \log\left(\frac{\|\Omega\|\left[k^2\Lambda + kM^2\right]}{\epsilon_E}\right)\right)$	$O\left(\frac{\|\Omega\|^2}{\epsilon_E}\left[k^2\Lambda + kM^2\right] \log^2 k\right)$
Amp. Qubitized IIIa	$O\left(\|\Omega\| \log k + \log\left\lceil\frac{\|\Omega\|\left(k^2\Lambda + kM^2\right)}{\epsilon_E}\right\rceil\right)$	$O\left(\frac{\|\Omega\|^2}{\epsilon_E}\left[k^2\Lambda + kM^2\right]\left[\log^4 k\right]\right)$
Amp. Qubitized IIIb	$O\left(\|\Omega\| \log k + \log\left\lceil\frac{\|\Omega\|\left(k^2\Lambda + kM^2\right)}{\epsilon_E}\right\rceil\right)$	$O\left(\frac{\|\Omega\|^2}{\epsilon_E}\left[k^2\Lambda + kM^2\right]\left[\log^2 k\right]\right)^*$

(in collaboration with C2QA)

T gate counts as a function of lattice size (left) and asymptotic logical gate and qubit count complexity (right) for computing scalar field scattering matrix elements using quantum phase estimation with various Trotter and qubitization based algorithms in both field and occupation bases. [5]

These inform long-term fault-tolerant architecture co-design for SQMS hardware.

Ongoing and future work includes: bosonic-LDPC quantum code concatenation, t-designs for qudit randomized benchmarking, quantum simulation with asymptotically optimal algorithms.

[1] "Benchmarking the algorithmic reach of a high-Q cavity qudit", N. Bornman et al., arXiv:2408.13317
[2] "Dual-Unitary Classical Shadow Tomography", A. A. Akhtar, N. Anand, J. Marshall, Y. You, arXiv:2404.01068
[3] "Uniformly Decaying Subspaces for Error Mitigated Quantum Computation", N. Suri, J. Saied, D. Venturelli, arXiv:2403.00163
[4] "Non-Binary Hypergraph Product Codes for Qudit Error Correction, " S. K. Borah, A. K. Pradhan, N. Raveendran, N. Rengaswamy, B. Vasić, the 2024 IEEE International Conference on Quantum Computing and Engineering (QCE) [accepted]
[5] "Optimized Quantum Simulation Algorithms for Scalar Quantum Field Theories", A. Hardy et al., arXiv:2407.13819

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This material is based upon work supported by the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers, Superconducting Quantum Materials and Systems Center (SQMS) under contract number DE-AC02-07CH11359.