Noise-Robust Estimation of Quantum Observables in Noisy Hardware

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Error mitigation is essential for counteracting noise in quantum computations until fault-tolerant quantum technologies become viable. Here, we introduce Noise-Robust Estimation (NRE), a noise-agnostic framework that systematically reduces estimation bias through a two-step post-processing approach. At its core, NRE exploits a previously unidentified bias-dispersion correlation, where a measurable metric—normalized dispersion—quantifies and helps suppress unknown residual bias in expectation value estimations. We leverage bootstrapping of measurement shots to construct a data set that reveals this correlation. We experimentally validate NRE on a IQM superconducting quantum processor executing quantum circuits with up to 20 qubits and 240 entangling CZ gates. Our results demonstrate that NRE consistently achieves near bias-free estimations across different implementation settings while maintaining a manageable sampling overhead. These findings establish NRE as a reliable and broadly applicable error mitigation method for quantum computation with noisy hardware.

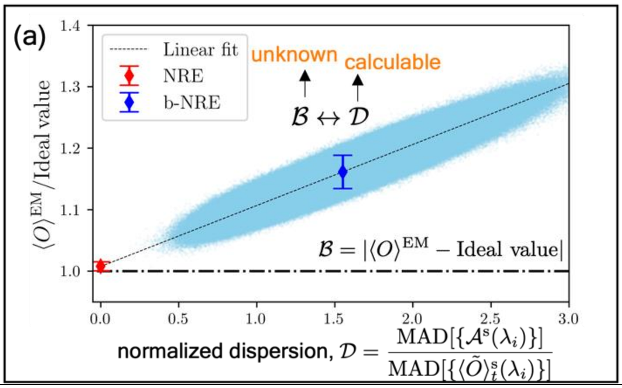

Figure 1: Experimentally observed correlation between the normalized dispersion and the residual bias error. The light blue shaded region represents a total of 8×10^6 baseline estimations, obtained from 2.4×10^5 measurement shots. The blue and red data points correspond to the mean and standard deviation of the baseline and final estimations, respectively.