Application-level benchmarking of quantum computers using nonlocal game strategies

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July 2025 Quantum Sci. Technol. 10 045002

Application-level benchmarking of quantum computers using nonlocal game strategies

- Nonlocal games natural candidates for benchmarking
- For some games, winning probabilities are known but strategies are not
- Game rules encoded into Hamiltonian
- VQE to find optimal strategy
  - Quantum strategy = $\underbrace{\text{Resource state}}_{\theta,\ \text{ADAPT-VQE}}$ + $\underbrace{\text{Input dependent measurement setting}}_{\phi}$

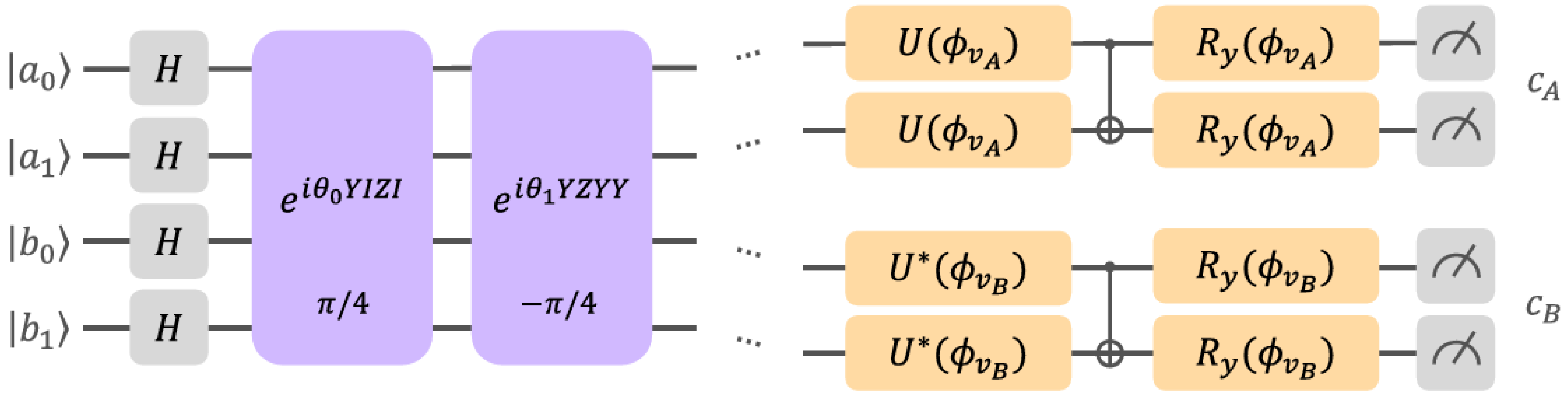

Figure 5. Generated circuit for G_{14}. The initial state $|+\rangle^{\otimes N}$ is prepared, then ADAPT added the operators Y_0Z_2 and $Y_0Z_1Y_2Y_3$, giving the shared state $|\psi(\theta)\rangle$. The remaining gate layers along with the 112 measurement parameters ϕ constitute the measurement strategy. We only adaptively added circuits on the state preparation and fixed the measurement scheme in this case.

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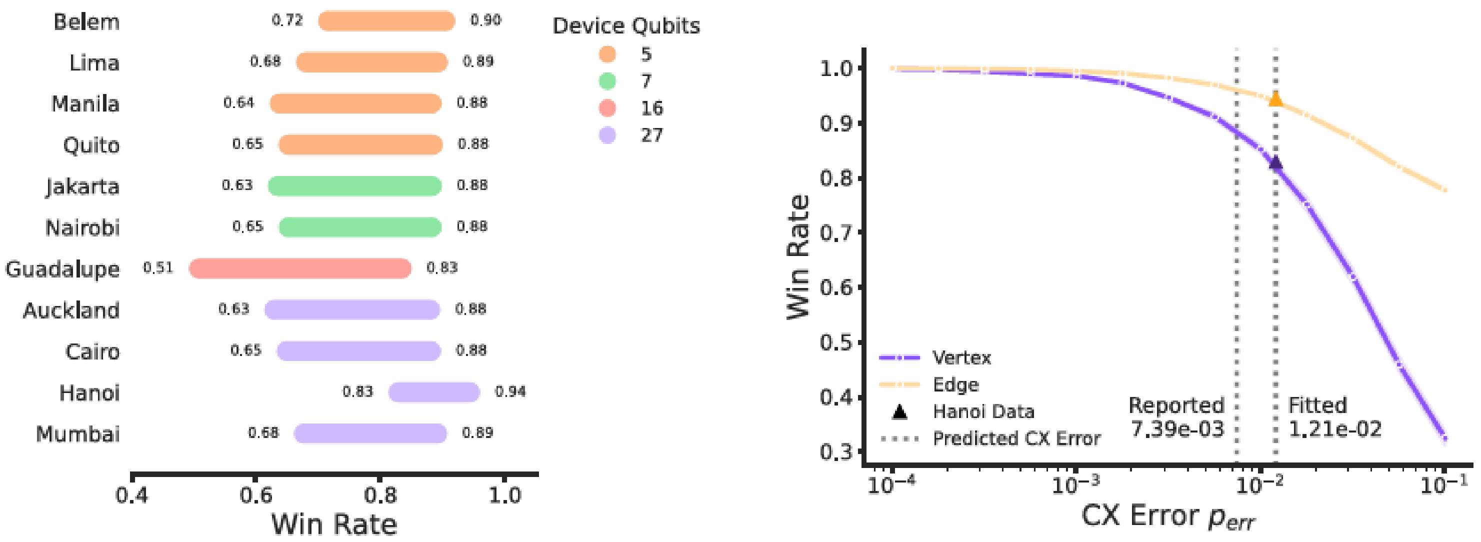
  - Quantum strategy = $\underbrace{\text{Resource state}}_{\theta,\ \text{ADAPT-VQE}}$ + $\underbrace{\text{Input dependent measurement setting}}_{\phi}$
- Gradient descent-like optimizer to find optimal params
- Finds optimal strategies for:
  - CHSH (caveat)
  - N-partite symmetric game (NPS)
  - Odd-cycle chromatic number game



(a) All devices

(b) Noise Simulation

Figure 8. (a) Average performance of the strategy on quantum devices grouped by question category, either a vertex $q = [v, v]$ or an edge $q = [v_1, v_2]$ (vertex winrate on the left, edge winrate on the right). The number of device qubits is reported to distinguish processor types; the circuit was executed on 4 qubits. (b) Classical simulation of the circuit with random Pauli noise applied to CNOT gates with probability p_{err}. The circuit was transpiled to the basis gates and coupling map of `ibm_hanoi`, and the observed data are fitted to the curves by maximizing the probability of observing the data assuming a normal distribution. The estimated error for CNOT gates is higher than reported, since our simulation did not account for measurement readout or decoherence errors.

- Vertex questions are more sensitive to bit flips
- Errors in entangling 2-qubit gates
- Also done for readout/measurement error

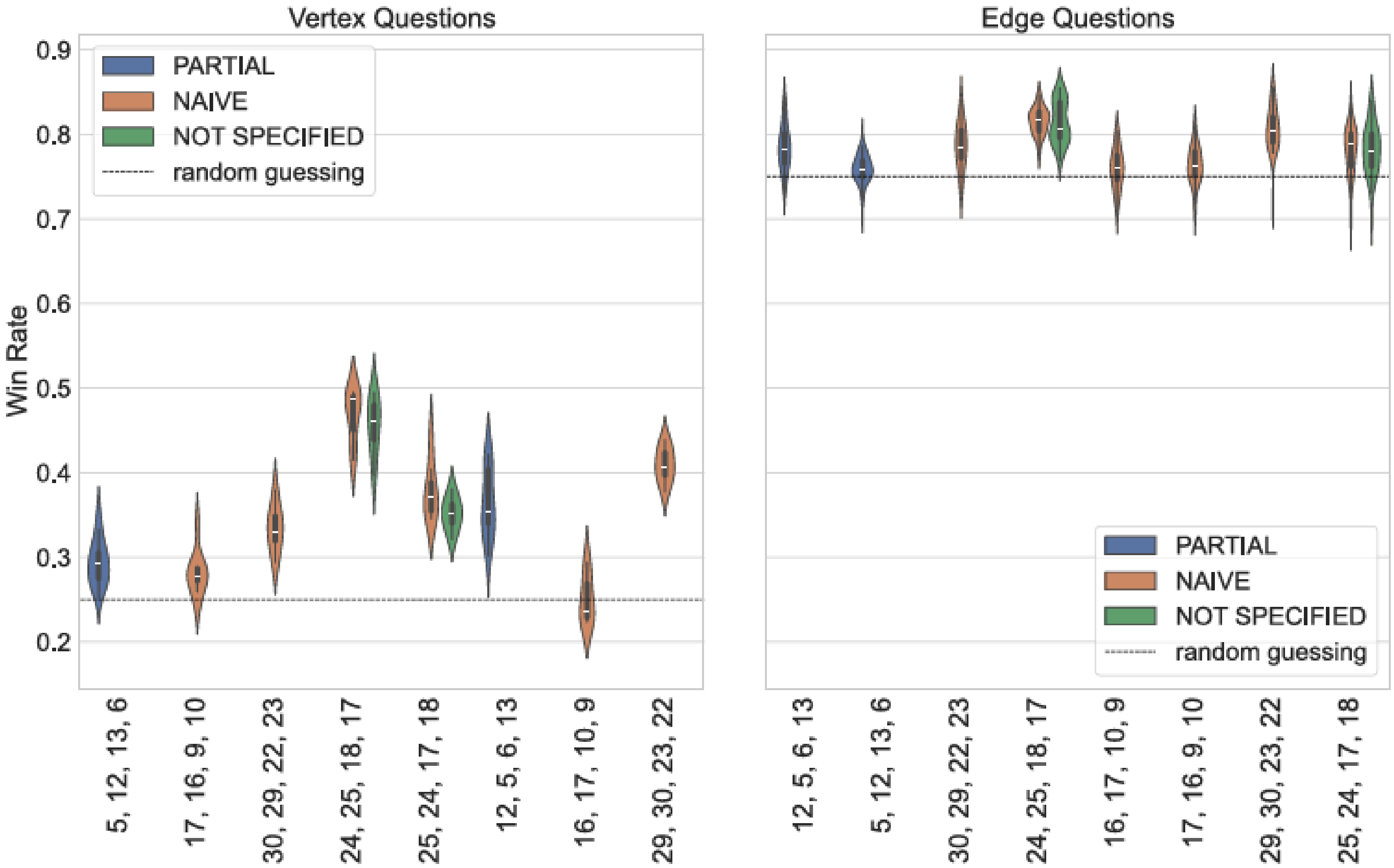


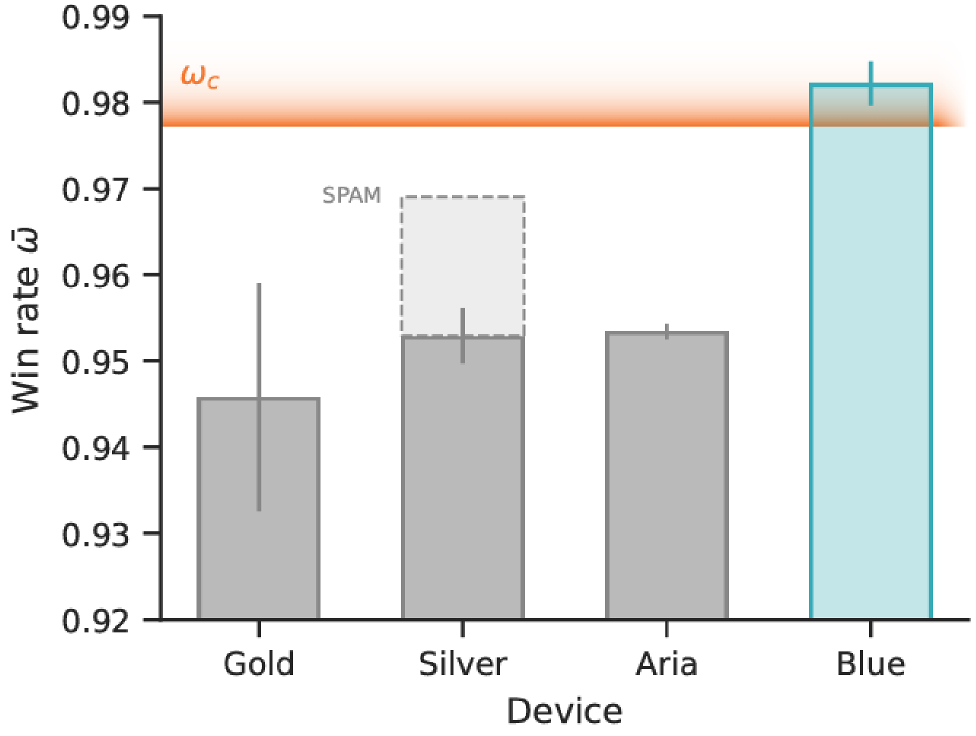
Figure 9. (Left) All vertex question win rates of the original G_{14} strategy grouped by hardware qubits used on Ankaa-2 from Rigetti. (Right) Edge question win rate of the original G_{14} strategy grouped by hardware qubits used on Ankaa-3 from Rigetti.

Nonlocal Games as Cross-Platform Quantum Benchmarks: Exceeding unconditional classical bounds on trapped-ion processors

Anton T. Than, Jim Furches, Debopriyo Biswas, Sarah Chehade, Kathleen Hamilton, Bahaa Harraz, Xingxin Liu, De Luo, Keqin Yan, Yichao Yu, Vivian Ni Zhang, Liudmila A. Zhukas, Alaina M. Green, Alexander Kozhanov, Christopher Monroe, Crystal Noel, Carlos Ortiz Marrero, Norbert M. Linke

18 Mar 2026, arXiv:2603.18323

- This outcome is attributed to its combination of high two-qubit gate fidelity and low measurement crosstalk



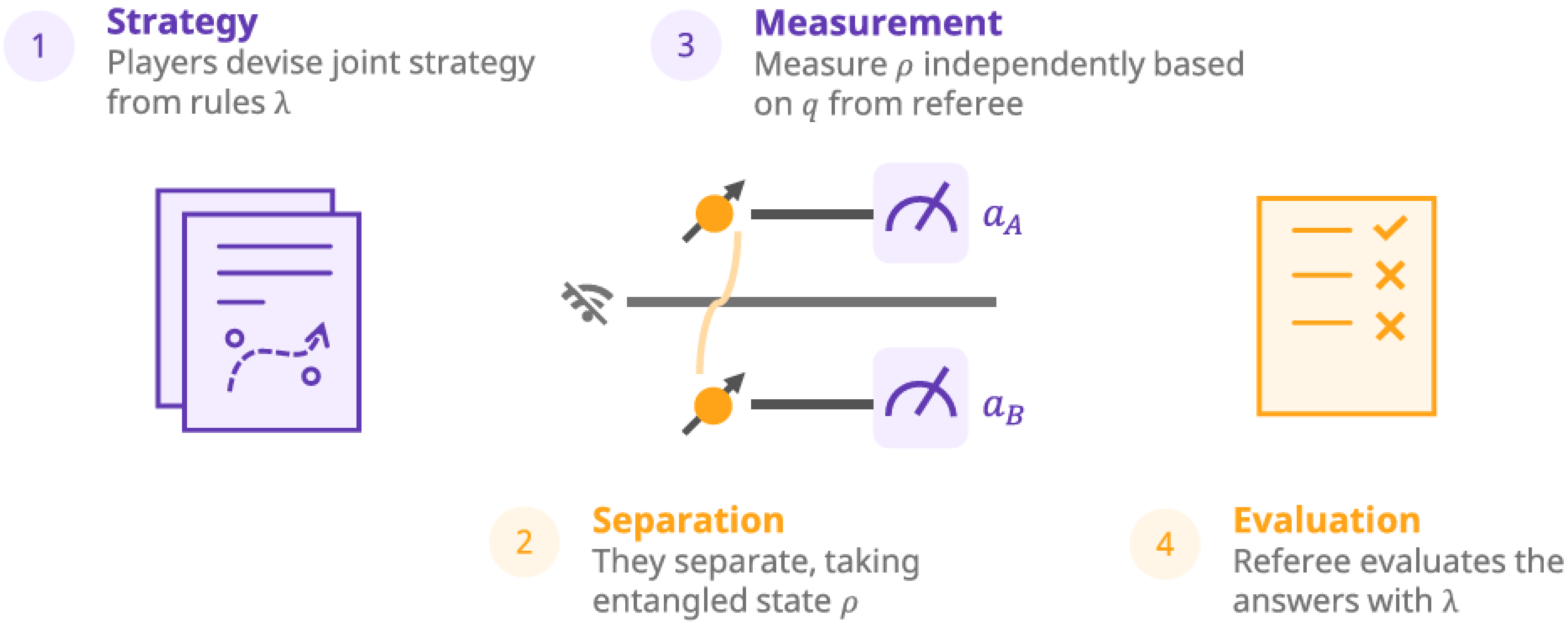


Figure 1. Flow of a nonlocal game. After formulating a strategy, Alice and Bob separate and cannot communicate. For a quantum strategy, they each take a part of an entangled state ρ and upon receiving a question q from the referee, they perform a measurement on their respective states, giving an answer $a \sim p(a|q)$. Finally, the referee receives their answers and verifies them against the rules $\lambda(a|q)$.

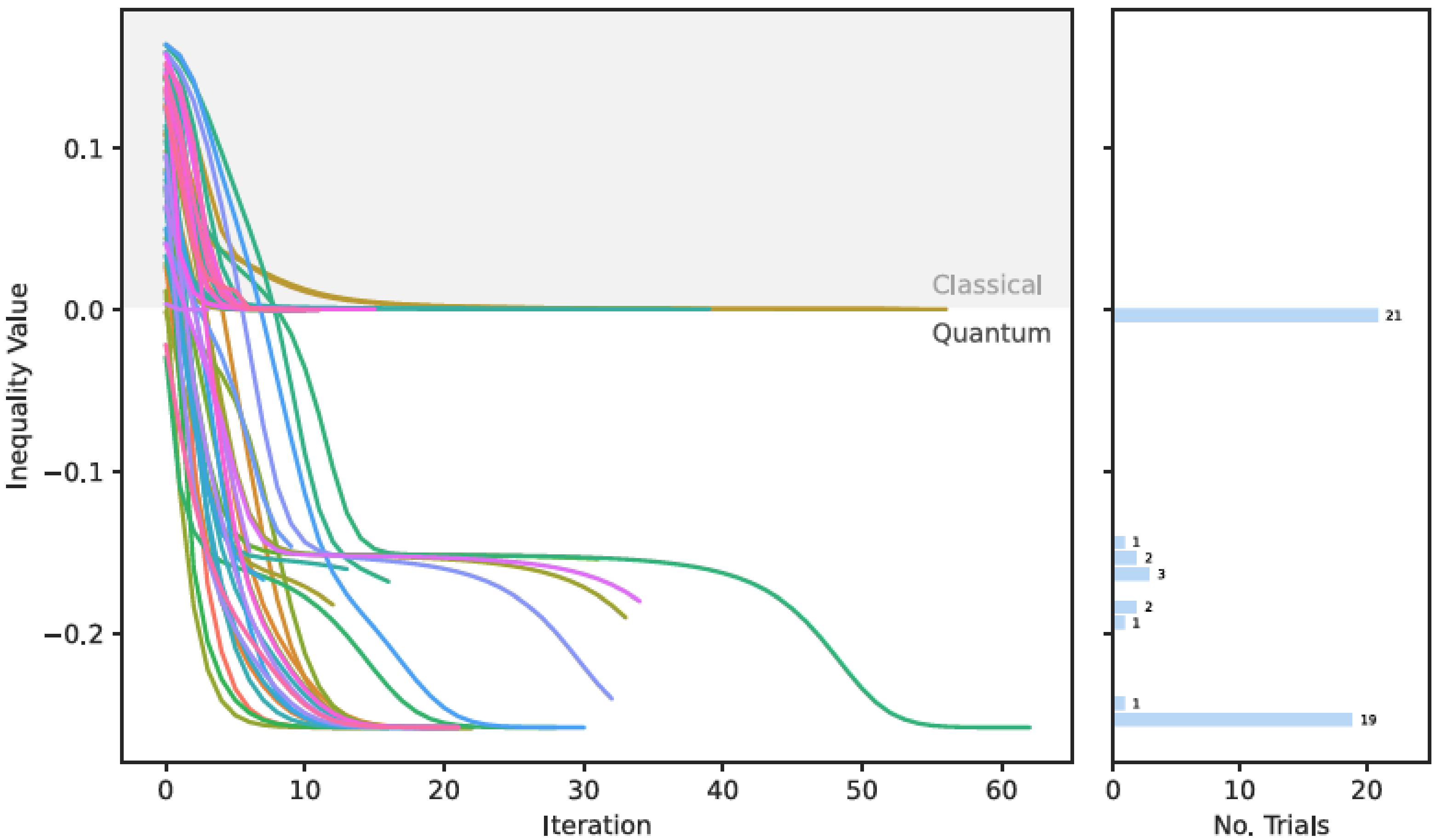


Figure 2. Trials of DPO on NPS for $N = 6$. (Left) Trajectory of all 50 trials. Negative inequality values are not reachable with classical states. (Right) Distribution of the final inequality values. Despite the non-convexity of the problem, many trials still reach the optimal value.

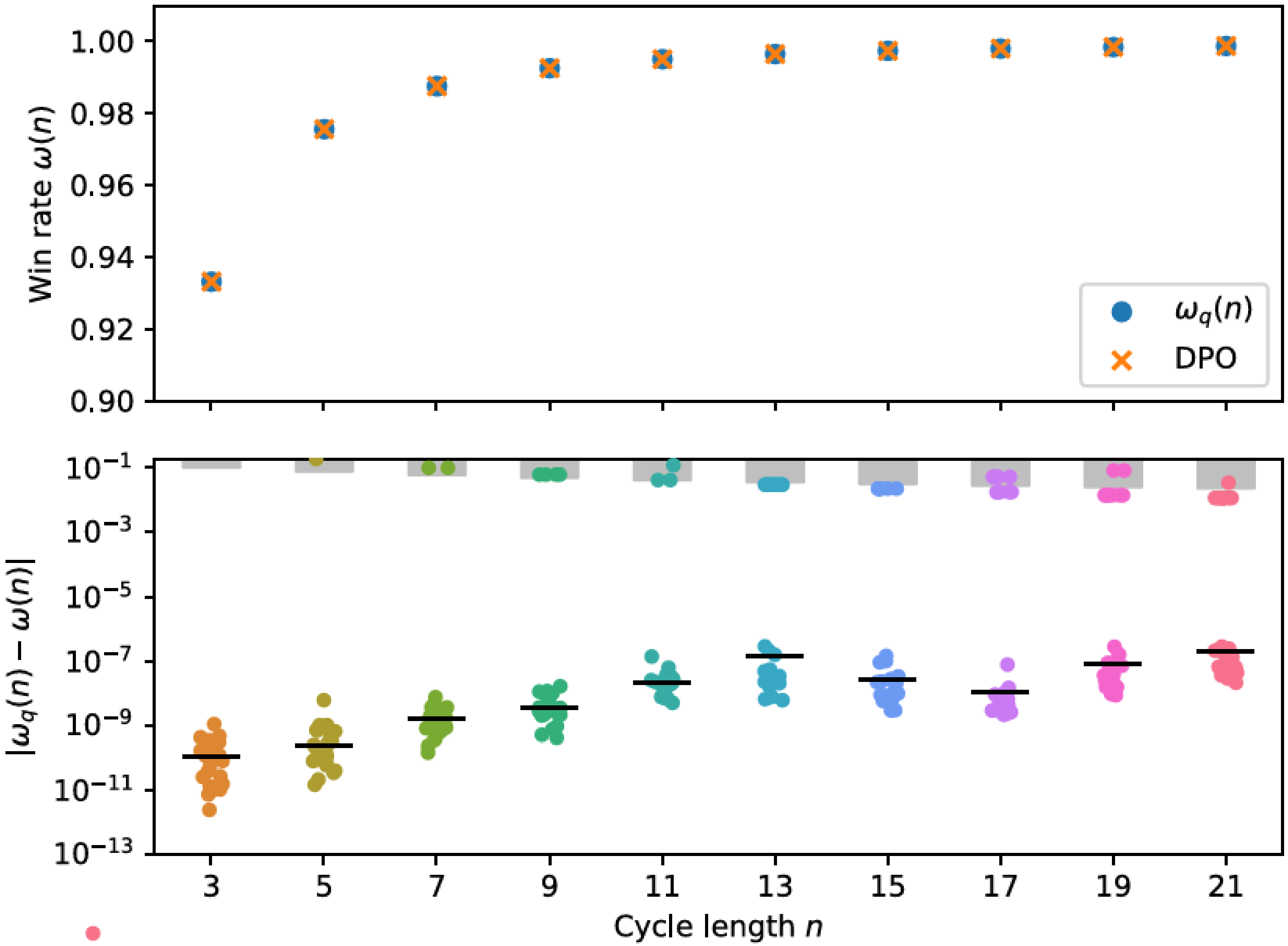


Figure 3. Win rates of discovered strategies for the odd-cycle game. (Top) The maximal win rate found for each game instance $G(n)$ compared to the optimal quantum value $\omega_q(n)$. (Bottom) The distribution of values for each instance. The black lines denote the median, and the gray regions correspond to the classical bound $\omega_c(n)$.