Optical Emulation of Bell Tests, Information Entropy, and QKD Protocols with Pulsed Lasers

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Emulation offers a useful framework for exploring quantum-information protocols in controllable classical and quantum platforms. In this talk, I present a hybrid approach combining pulsed-laser optical emulation, IBM superconducting quantum-computer experiments, and machine-learning reconstruction methods for studying Bell-type correlations and related quantum-information protocols.

The optical system uses polarization-encoded pulsed laser pulses, basis-selective measurements, and time-resolved detection to reproduce the algebraic structure of Bell-state analysis, including effective density-matrix reconstruction and CHSH-type correlation matrices. In parallel, IBM quantum hardware implements a two-qubit CHSH circuit in which entanglement is generated through a Hadamard-CNOT sequence, converted to the $|\psi^+\rangle|\psi^+\rangle$ Bell state, and measured after programmable RyRy rotations of Alice and Bob's measurement axes. These data provide a genuine quantum reference for comparison with the optical emulator.

A central direction of this work is the use of machine learning to reconstruct incomplete Bell-test data. In a standard CHSH experiment, the Bell parameter is obtained from 16 measurement-angle settings, but realistic free-space, satellite, photonic, and matter-wave systems may lose settings because of turbulence, obstruction, detector dead time, or finite acquisition time. We show that supervised models can infer a missing correlator and recover the Bell parameter from only 15 of the 16 settings.

This strategy is validated across IBM quantum hardware, the MIT optical Bell-test emulator, single-photon entangled-pair data, and metastable-helium atom-pair Bell-test data. The results suggest a practical route toward stabilizing Bell certification and QKD protocols against partial measurement loss, while providing a compact platform for studying how quantum-style correlations are encoded, reconstructed, and certified.

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