Teleportation of vacuum—one-photon qubit states generated by quantum dot-based single-photon sources

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Abstract: Quantum teleportation has been demonstrated in many photonics platforms, but Fock-based encoding is challenging. Here, we show the teleportation of vacuum-one-photon qubits using a quantum dot in micro-cavity, offering the potential for quantum information processing.

Single-photon sources based on semiconductor quantum dots are optimal solutions in several applications in quantum information processing due to their high single-photon indistinguishability, on-demand generation, and low multiphoton emission [1]. Furthermore, the resonant excitation scheme, in which the wavelength of the pump laser matches the emission line of the quantum dot, enables the generation of states in superposition on the Fock photon number basis [2]. In this context, quantum state teleportation is a fundamental protocol in quantum information to develop large-scale quantum networks. While there have been successful demonstrations using various qubit encodings, achieving teleportation with Fock basis encoding has proven difficult. This challenge arises because creating a coherent superposition of vacuum and one-photon states in a single mode using linear optics is not feasible. Previous attempts in such an encoding focused on teleporting dual-rail entangled states, relying on auxiliary electromagnetic modes. In this work, we demonstrate the teleportation of genuine vacuum-one-photon qubits encoded in a single spatial mode like $|\psi\rangle = \alpha|0\rangle + e^{i\phi}\beta|1\rangle$ through the coherent control of a semiconductor quantum dot in a micro-cavity (Fig. 1a). Our approach enables the teleportation of such quantum states through the apparatus shown in Fig. 1b, that allowed us to make interfere the quantum states generated at different times by the quantum dot through time-to-space demultiplexing and fiber delays. The experimental results of the teleportation are summarized in Fig. 1c. We compared the visibility of the fringes observed at Bob's station conditioned to Alice's measurement outcomes with a scenario that exploits only classical resources. These results open up new possibilities for quantum information processing using this encoding, facilitated by quantum dot single-photon sources [3].

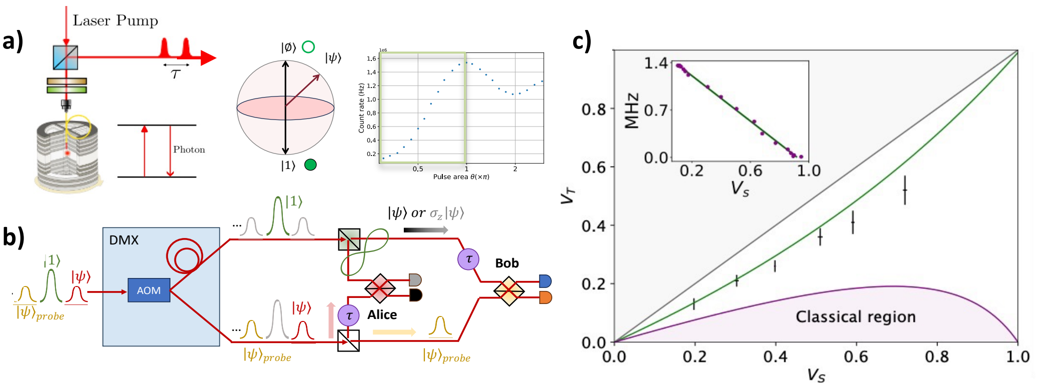

Fig. 1 Teleportation of vacuum—one-photon qubits. a) A semiconductor quantum dot in a micropillar cavity generates a coherent superposition of vacuum and one-photon components when excited by a resonant optical pulse between 0 and pi-pulse power (see Rabi oscillation in the inset). b) Experimental apparatus for quantum teleportation which processes three single-photon states from the source via a time-to-space demultiplexer (DMX) through acoustic-optical modulation (AOM), fiber delays, and two-photon interference on unbiased beamsplitters. c) Benchmarking of the protocol via the comparison of the fringe's visibility detected at Bob's station when the teleported state interferes with a copy of the original qubit. The experimental data are far more than two standard deviations from the classical scenario. Figures from [3].

References

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