Experimental optimal cloning of four-dimensional quantum states of photons

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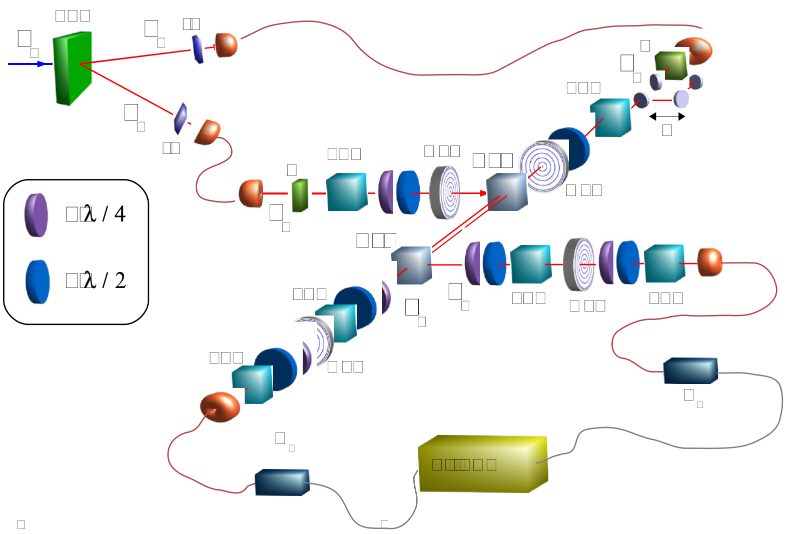
Optimal quantum cloning is the process of making one or more copies of an arbitrary unknown input quantum state with the highest possible fidelity. Before the present work, all reported demonstrations of quantum cloning have been limited to copying two-dimensional quantum states, or qubits. In this paper, the authors report the first experimental realization of the optimal quantum cloning of four-dimensional quantum states, or ququarts, encoded in the polarization and orbital angular momentum (OAM) degrees of freedom of photons. The effective and flexible control and analysis of the OAM photonic state that was essential to obtain this result was made possible by the q-plate technology, developed by Lorenzo Marrucci, of CNR-SPIN, and his coworkers. The employed quantum-cloning procedure is also shown in the paper to be generally applicable to quantum states of arbitrarily high dimension—or qudits—and to be scalable to an arbitrary number of copies, in all cases remaining optimal. Furthermore, the authors report the bosonic coalescence of two single-particle entangled states.



Sketch of the experimental setup used to demonstrate the optimal quantum cloning of four-dimensional photonic states. The cloning takes place in the beam-splitter BS1, thanks to a bosonic quantum coalescence effect. All remaining optics is used to set the input photon states and to analyze the output ones (see article for details). In particular, the q-plate devices QP# are used to control the OAM state of the photons.