Weak values and the direct measurement of the quantum wavefunction

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In a paper recently published in Nature Photonics [1], our group describes a procedure for measuring directly the polarization state of a photon of light. Until recently, the quantum state of light could be measured only using indirect procedures, such as quantum tomography. Quantum tomography requires intensive post-processing of the data, and this is a time-consuming process that is not required in the direct measurement technique. Thus, in principle, the new technique provides the same information as quantum tomography but in significantly less processing time. The concept of direct measurement was first introduced in 2011 by Jeff Lundeen and his coworkers [2]. Our new work builds on this earlier work by applying it to the polarization degree of freedom of the light field for qubits, the building blocks of quantum information science.

The key to characterizing any quantum system is the gathering of information about conjugate variables. The reason it was previously thought impossible to measure two conjugate variables directly was because measuring one would destroy (collapse) the wavefunction before the other one could be measured. The direct measurement technique employs a "trick" to measure the first property in such a way that the system is not disturbed significantly and information about the second property can still be obtained. This careful measurement relies on the "weak measurement" [3] of the first property followed by a "strong measurement" of the second property.

The ability to perform a direct measurement of the quantum wavefunction has important implications for quantum information science. Ongoing work in our group involves applying this technique to other systems, for example, measuring the form of a "mixed" (as opposed to a pure) quantum state and to measuring the statevector of a state imbedded in a very large Hilbert space.

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Fig. 1 Experimental setup used to measure the polarization statevector of a photonic qubit.