Two-photon interference and Bell-state measurement with weak laser pulses recalled from separate solid-state quantum memories

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The reversible transfer of quantum information between light and matter is key to the development of quantum repeaters [1], quantum networks [2], as well as for linear optics quantum computing [3]. A lot of progress has been reported over the past few years, including the faithful transfer of information from photons in pure and entangled qubit states [4-7]. However, none of these demonstrations suffice to show the possibility for two-photon measurements after quantum state storage, e.g. for performing C-NOT gates or for projections onto Bell states, which are required for all applications of quantum information processing mentioned above. Indeed, for these measurements to succeed, the two photons need to be indistinguishable in all degrees of freedom, which is more restrictive than the requirement of faithful recall of encoded quantum information. Taking into account that photons may or may not have been stored before the measurement, this criterion amounts to the necessity that a quantum memory does not modify a photon's wave function during storage.

In this work we demonstrate two-photon interference and a Bell-state measurement with attenuated pulses of light (featuring an average of less than one photon per pulse) that have, or have not, been reversibly mapped to separate thulium-doped lithium niobate waveguide quantum memories using a photon-echo type approach based on an atomic frequency comb [8]. As the interference visibility is close to the theoretical maximum, regardless of whether none, one, or both pulses have previously been stored, we conclude that our solid-state quantum memories preserve the entire photonic wave function during storage. This finding completes a missing step towards advanced applications of quantum information processing, and brings us closer to building quantum repeaters, networks, and linear optics quantum computers.

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