Entangling a Quantum Dot Hole-Spin with a Time-Bin Photon: A Waveguide Approach for Scalable Entanglement Generation

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Deterministic sources of multi-photon entanglement are essential for several quantum technologies including measurement-based quantum computing [1] and all-photonic quantum repeaters [2]. Solid state quantum dots (QDs) are an attractive platform for realizing such sources due to their excellent optical properties, the ability to host a single optically active spin qubit, and the possible integration into nanophotonic devices [3]. Here we demonstrate a new path towards on-demand Greenberger-Horne-Zeilinger and linear cluster states using a self-assembled InAs QD embedded in a photonic crystal waveguide (PCW). By combining the waveguide's polarisation selective Purcell enhancement [4] with all-optical spin control (Fig. 1(a-b)), we perform the first demonstration of entanglement between a QD hole-spin and a time-bin photon using the protocol in Fig. 1c. Using a novel self-stabilizing interferometer, we measure a 67.8% spin-photon Bell state fidelity (Fig. 1(d-e)), a 95.7% photon Hong-Ou-Mandel visibility, and a 124 Hz coincidence rate in great excess of comparable experiments with nitrogen-vacancy centres. Based on a thorough theoretical analysis and numerical simulations, we provide a path towards efficient entanglement sources capable of generating long streams of photons emitted at 10s of MHz and with photon indistinguishability suitable for achieving high fidelity fusion gates.

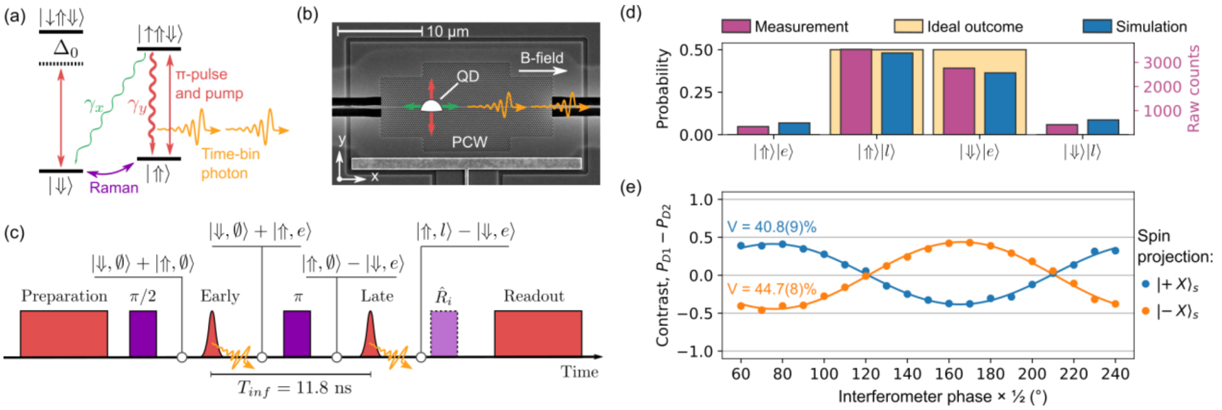

Fig. 1 (a) Positively charged QD energy level diagram. A cycling transition (red arrow) is used to emit the time-bin photon and perform spin initialization/readout, and a Raman laser coherently couples the ground state spins. (b) SEM picture of the PCW which selectively enhances the y-polarised optical dipole and provides efficient photon collection. (c) Experimental pulse sequence for Bell state generation. Ø denotes photon vacuum, and e and l denote an early or late photon emission, respectively. (d) Spin-photon correlations measured in the ZZ basis. (e) Spin-photon correlations measured in the rotated basis using a time-bin interferometer.

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