Continuous Generation of an Indistinguishable Photonic Cluster State

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Cluster states are multi-qubit entangled states that maintain their entanglement even if few of their qubits are measured, or even lost [1]. Cluster states of entangled photons are resources for measurement-based quantum computing and quantum communication protocols [2–3]. Demonstrating that a solid-state device can deterministically generate a photonic cluster state is a key to enabling these emerging technologies [4].

Here, we use a semiconductor-based quantum knitting machine that continuously and deterministically generates an indistinguishable multi-photon cluster state at a sub-GHz generation rate. Our device realizes a protocol proposed by Lindner and Rudolph [4], in which the quantum dot confined heavy-hole is used as a photon's entangler [5-7]. We use an externally applied magnetic field in Voigt configuration to tune the spin precession rate to achieve optimal entanglement length and to match exactly one-quarter of the precession to the pulse repetition rate. Thus, a single cycle of the protocol repeats itself indefinitely.

We characterize the generated cluster state by polarization tomography of a multi-photon state in which the first and last photons are projected on a circular polarization base. This way, the photons are disentangled from the quantum dot confined heavy hole qubit, resulting in an all-photonic cluster state. By detecting 4 sequential photon events, we demonstrate the concept of an all-photonic cluster state, and we quantify the robustness of the cluster entanglement. In addition, by tomography measurements of sequential events in which one photon was not detected, we demonstrate unambiguously that the device photon generation is deterministic.

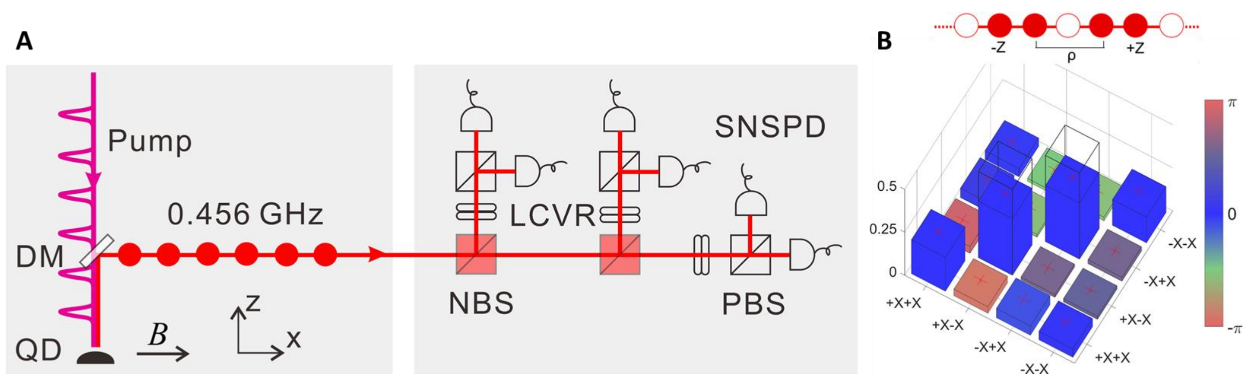

Fig.1. **A.** Schematic of entanglement generation and measurement. In the left panel, the laser's repetition rate is tuned to the hole's precession and the QD continuously emits a photonic cluster state. In the right panel, up to 6 photons' polarization are projected and their detection times are correlated. **B.** Two-photon polarization density matrix from a string of five photons. The first and last photons are projected on circular polarization and the middle photon is not detected.

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