

Reconfigurable four-photon graph states on a silicon chip

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Abstract

Integrated quantum photonics has so far been constrained to two on-chip generated photons. We present the first device to wield four-photon entanglement, generating both the star and line graph states. Further, we measure record levels of on-chip quantum interference. Finally, we bound the leading sources of error, combining a detailed model of the device with Bayesian parameter estimation, paving the way to scalability.

Quantum computers promise a paradigm shift in humanity’s capability to process information. Meanwhile, measurement-based quantum computing—based on graph states—provides the prevailing architecture for large-scale quantum computation [1]. Silicon quantum photonics is a high-performance, scalable quantum technology platform, boasting circuits of unparalleled scale [2], and simultaneous indistinguishable photon pairs [3].

Here, we generate both kinds of four-photon graph state using a silicon chip. Four on-chip sources of spontaneous four-wave mixing generate two Bell pairs in four dual-rail qubits. The Bell pairs are then entangled using a two-qubit gate, programmably generating either star and line type graph states—a first in optics. Then, reconfigurable local operations rotate the state into any of the other four-qubit graph states and implement measurement projectors. The photons are subsequently detected off chip by superconducting nanowire single photon detectors. Fig. 1a shows a schematic of the device.

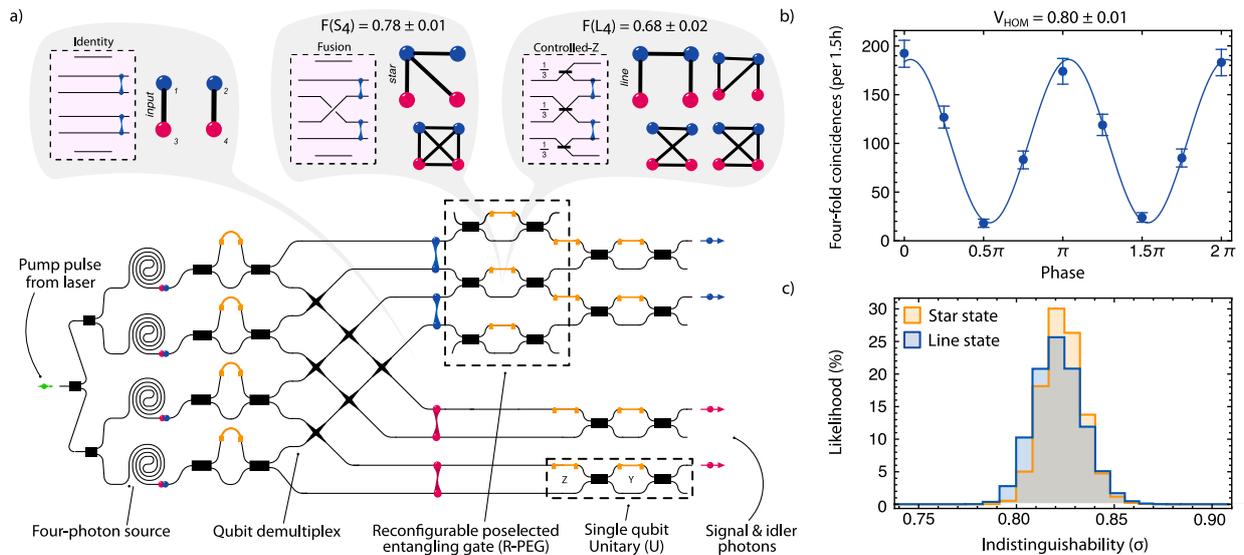


Fig. 1: a) Overview of the experiment. Star and line graph states are shown with their locally equivalent states and fidelities. b) A fringe demonstrating record on-chip HOM interference. c) Bayesian parameter estimates of on-chip photon indistinguishability.

Our star and line graph states have fidelities of 0.78 ± 0.01 and 0.68 ± 0.02 respectively. Further, our on-chip Hong-Ou-Mandel (HOM) interference visibility, $V_{\text{HOM}} = 0.80 \pm 0.01$, is state of the art, verifying our photons’ purity (see Fig. 1b). We also bound the device’s dominant sources of error by Bayesian parameter estimation (e.g. Fig. 1c). Our device breaks the multiphoton barrier for integrated quantum photonics, and demonstrates programmable entanglement generation, expediting progress towards quantum computing with photons.

- [1] R. Raussendorf, *Measurement-based quantum computation with cluster states*, International Journal of Quantum Information **7**, 1053–1203 (2009).
- [2] J. Wang et al., *Multidimensional quantum entanglement with large-scale integrated optics*, Science, eaar7053, (2018).
- [3] I.I. Faruque et al., *On-chip quantum interference with heralded photons from two independent micro-ring resonator sources in silicon photonics*, Optics express, **26**, 20379–20395 (2018).