Experimental validation of Threshold Quantum State Tomography with a fully-reconfigurable photonic integrated circuit

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Abstract: We show experimentally in an integrated photonic platform a threshold quantum state tomography technique to reconstruct quantum states with reduced number of projectors, achieving a good agreement with the complete quantum state tomography results.

Quantum state tomography (QST) is the standard technique to reconstruct the state of a quantum system. However, the required resources of the protocol increase exponentially with the size of the quantum system [1]. A novel approach, known as threshold quantum state tomography (tQST), provides a strategy to determine the number of resources for an optimal reconstruction of a quantum state with no requirement to have prior knowledge of the state [2]. In this work, we reconstruct density matrix of path-encoded quantum states with up to four photons, implementing tQST on a fully reconfigurable photonic integrated circuit. We demonstrate that quantum states can be reconstructed with the same accuracy as QST with a complete set of projectors (full QST), significantly reducing the number of measurements.

The setup can be described by three main blocks. 1) **Photon source:** a semiconductor Quantum Dot (QD) and a time-to-spatial demultiplexing (DMX) cooperates in the generation of multi-photon states. 2) **State preparation:** multi-photon states are injected into a eight-mode fully reconfigurable photonic integrated circuit (PIC) with a universal rectangular layout. The cyan section of the PIC, involved in the state generation, is shown in Fig. 1 (a). Dual rail logic and post-selection measurements are employed. 3) **State measurement:** projectors are implemented in the blue section of Fig. 1 (a). Output photons are routed towards a superconductive detection system connected to a time-to-digital converter, registering n-fold coincidences events.

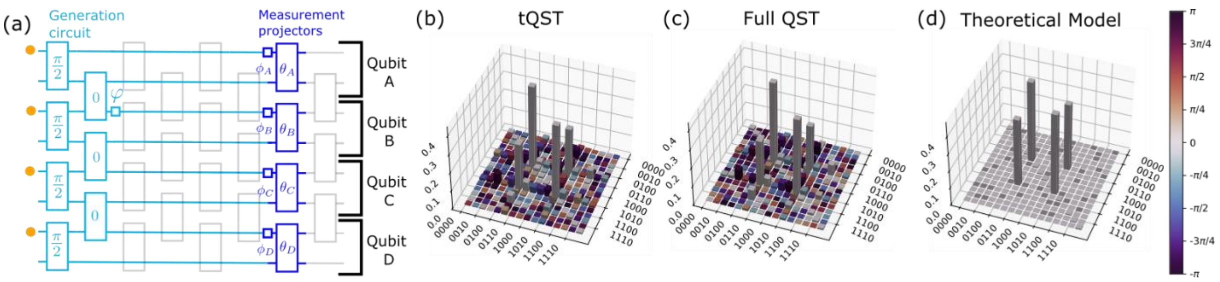

Fig. 1 Reconstruction of a four-photon GHZ state. (a) Scheme for the generation of a 4-photon GHZ state $|GHZ_4\rangle = (|0101\rangle + e^{i\phi}|1010\rangle)/\sqrt{2}$ (cyan-coloured section) and the implementation of the single-qubit measurement projectors (blue-coloured section). (b) State density matrix reconstructed by tQST, (c) full QST, and (d) simulated density matrix considering the noise derived from the quantum dot source and losses.

The density matrices of a four-photon GHZ state reconstructed using tQST (requiring 60 projective measurements) and full QST (using all the 256 required projective measurements) are presented Fig. 1 (b) and (c). Fig. 1 (d) displays the expected density matrix obtained taking into account the setup noise. Analogous measurements are performed for different quantum states of 2, 3 and 4 qubits, thus showing the effectiveness of the techique.

In conclusion, tQST provides a state reconstruction approach with fewer projectors than full QST with comparable accuracy. This substantial reduction in the number of exploited recources becomes particularly relevant to scale state reconstruction for large dimensional quantum states.

Example References

[1] D. F. V. James, et al., "Measurement of qubits," Phys. Rev. A, 64, 052312 (2001).

[2] D. Binosi, et al., "A tailor-made quantum state tomography approach," APL Quantum 1, 036112 (2024)