

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

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Abstract: we implement threshold quantum state tomography on a fully reconfigurable photonic integrated circuit, reconstructing density matrix with reduced number of projectors and achieving a good agreement with the complete quantum state tomography results.

The reconstruction of a quantum state, through Quantum state tomography (QST), requires that the resources of the protocol increase exponentially with the size of the quantum system. A novel approach, known as threshold quantum state tomography (tQST), determines the number of resources for an optimal reconstruction of a quantum state with no requirement to have prior knowledge of the state [1]. 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 [2]. We demonstrate that quantum states can be reconstructed with the same accuracy as QST, significantly reducing the number of measurements.

The experimental setup exploits a semiconductor Quantum Dot (QD), jointly with a time-to-spatial demultiplexing (DMX) and an eight-mode fully reconfigurable photonic integrated circuit (PIC). State generation and projection take place both on the PIC. Output photons are routed towards a superconductive detection system connected to a time-to-digital converter, registering n-fold coincidences events.

As a first step, the tQST technique was validated on two sets of 2-qubit and 3-qubit quantum states. Then the technique was applied to maximally-entangled states up to a maximum of 4 qubits. Figure 1 shows the density matrices, obtained by maximum likelihood estimation on the raw experimental data, for maximally-entangled states with the two different approaches: QST (Panels a-d) and tQST (Panels e-g).

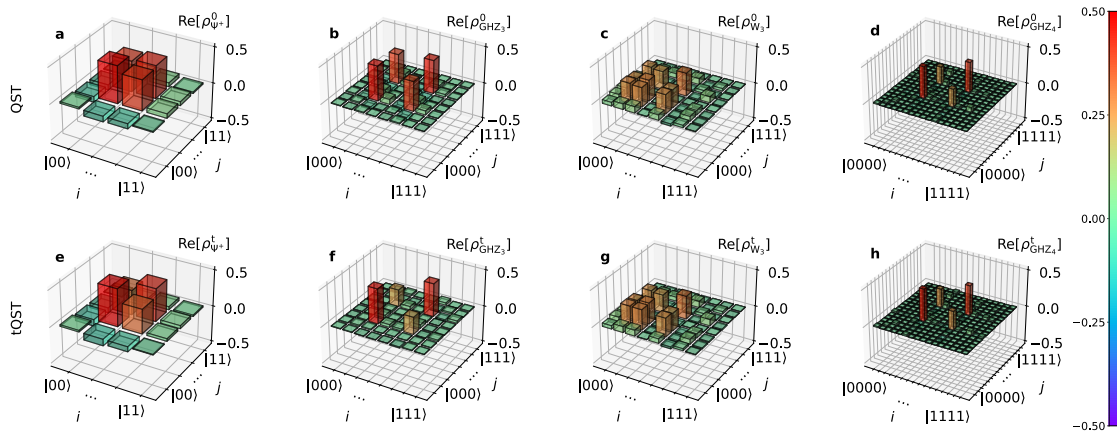


Fig 1: Real part of the reconstructed density matrices ρ_α^0 and ρ_α^t for maximally entangled n -qubit states through, respectively, the QST (Panels a-d) and tQST (Panels e-h) approach, with $\alpha = \Psi^+, GHZ_3, W_3, GHZ_4$.

It is highlighted how, in the case of the 4-photon GHZ state $|GHZ_4\rangle$, the number of projectors involved in the reconstruction is equal to 256 for QST and 66 for tQST. The fidelity of $\sim 95\%$, between the density matrices of the two approaches, for the state $|GHZ_4\rangle$, suggests that the tQST technique permits to reconstruct the quantum state with a moderate information leakage.

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

Example References

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

[2] E. Caruccio, et al., "Experimental verification of threshold quantum state tomography on a fully-reconfigurable photonic integrated circuit", *npj Quantum Information* **11**, 173 (2025).

