Temporal synthetic photonic lattice for quantum information processing

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Abstract: We present the theoretical design and experimental implementation of a programmable synthetic temporal photonic lattice enabling control over quantum light flow. This capability allows for time-bin two-photon entangled state preparation, manipulation, and quantum interference measurements.

Conventional all-optical quantum circuits control quantum light flow through spatially separated optical paths connected via beam splitters [1]. These devices require precise alignment with multiple elements. Alternatively, synthetic photonic lattices (SPLs), where the optical path is replaced by a photonic degree of freedom [2], offer a scalable and resource-efficient alternative for simulating phenomena like parity-time symmetry [3]. However, the use of SPLs for quantum information processing has remained unproven in the lab. Here we present our results on the first experimental realization of a SPL via an unbalanced fiber-loop configuration with a variable central coupler to control light flow. The design of the controllable temporal SPL allows us to perform quantum information tasks, such as two-photon state preparation, manipulation, and interference measurements [4].

Pulses propagate multiple roundtrips to generate classical pulse sequences, then passing through periodically poled lithium niobate waveguides to generate two- or four-level time-bin-entangled photon pairs via spontaneous parametric down-conversion. In the case of qubit interference, as depicted in Fig. 1(a) below, the dynamic central coupler directs earlier time-bin photons into the long loop and reflects later time-bin photons into the short loop. During the second roundtrip, both bins interfere at the 50:50 coupler. Coincidences between photons from the short loop are measured for different relative phases between consecutive time bins (Fig. 1(d)). The measurement process is without post-selection, yielding a raw visibility $V_2 = 96.83\%$. In the qudit (d = 4) case, as illustrated in Fig. 1(c), the first two time bins are transmitted into the long loop, while the remaining two are reflected into the short loop. During the second roundtrip, all four bins are reflected within their respective loops. During the final two roundtrips, the coupler is set to 50:50 to enable interference. Then, we measure the coincidence within a specific window for different relative phases (Fig. 1(e)), getting a raw visibility $V_2 = 89.61\%$. We repeat the measurement with classical light and compare its normalized intensity to the quantum interference pattern.

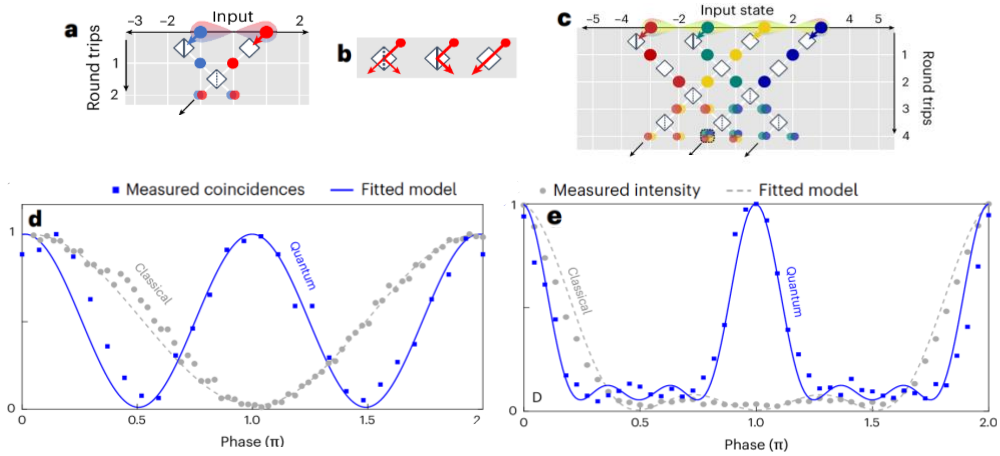

Fig. 1. Qubit interference **(a)**; functional operators **(b)**; qudit interference **(c)**; normalized coincidence counts of entangled qubits **(d)** and entangled qudits **(e)**, together with classical light intensity, as a function of the relative phase difference between time bins.

References

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