Quantum simulation of spin chain dynamics via integrated photonics

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Photonic circuits represent a promising platform to perform quantum simulation of several different physical phenomena. Indeed, large progresses have been achieved in the last few years due to the technological advances enabled by integrated photonics, which allowed to achieve a significant increase in the size of the implemented systems. Notable examples of observed phenomena in integrated circuits include Anderson localization [1] and transport mechanisms [2].

We discuss the photonic simulation of spin chain dynamics after a quench in a 5-site system [3]. Such dynamics present the feature of entangling distant spins in pairs starting from the input (separable) Neel state, thus obtaining an amount of entanglement which is proportional to the number of sites present in the system (volume law [4]). The verification of such increase in the amount of the generated entanglement provides a useful resource for several quantum information protocols, including quantum teleportation and quantum networking.

The photonic simulation of such a system requires several ingredients. Spin excitations in a chain with nearest-neighbour interactions are mapped onto non-interacting fermions hopping in a lattice. Fermionic statistics is then mimicked by exploiting the symmetry of the two-photon input in the polarization degree of freedom. Hence, the photonic circuit performing the simulation must be polarization independent. Such feature is enabled by the 3-dimensional capabilities of femtosecond laser-writing technique. To simulate the evolution of the spin chain, and detect the entanglement generated in the output state, two integrated devices have been implemented. In a first device, the parameters of the circuit (directional coupler transmissivities and phases) are properly engineered to mimic the dynamics of the spin chain. By exploit the polarization degree of freedom, both fermionic and bosonic statistics after evolution have been investigated through the same dynamics (Fig. 1). A second reconfigurable integrated circuit has been then implemented to detect the entanglement between distant sites generated by the dynamics. This device directly interferes distant output modes after the evolution through the first circuits, thus permitting to recognize the presence of entanglement.

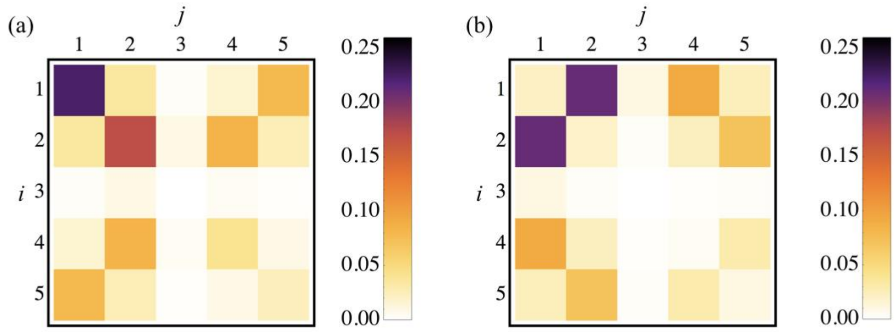

Fig. 1 Output correlation matrix between sites i and j after evolution through the first device mimicking the 5-site dynamics for (a) bosonic statistics and (b) fermionic statistics.

The obtained results show that photonic circuits represent a promising toolbox to perform the investigation of a large set of many-body dynamics.

References

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