Novel approach for the implementation of quantum walks in linear-optics setups

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The field of quantum computation and quantum simulation has been recently driven to a new rising edge by the experimental realization of quantum walks in various setups, highlighting that different physical systems can be adapted for the implementation of these models. In particular, optical systems have shown their full potential, allowing the experimental demonstration of two-dimensional quantum walks for the first time [1], even if several further progresses will surely be obtained also in the other physical scenarios that have been already exploited for the one-dimensional case [2]. It is expected that striking results will be experimentally found when the technology will allow proper control of two- or multi- dimensional models.

Two approaches have been mainly used so far for the optical implementation of quantum walks. The first encodes the coin degree of freedom into the polarization of a photon (in the case of higher-dimensional coin space, additional degrees of freedom are needed), and the position degree of freedom into its arrival time. The quantum walk is then realized by means of polarizing beam splitters and optical loops. Interestingly, the setup requires a fixed number of optical elements regardless of the number of time steps that one wants to obtain, the latter being limited only by the losses and the detection stage. The second approach follows the idea proposed in Ref. [3], where an array of beam splitters is exploited in order to implement a quantum walk. In this scenario, the position of the walker corresponds to the actual position of the photon on a particular axis, and the coin degree of freedom corresponds to the incoming direction of the photon at a particular beam splitter. The model can be straightforwardly mapped into an integrated waveguide circuit (see, for instance, Ref. [4]) and can therefore benefit from all the advantages of this setup. The drawback is that the number of elements grows at least quadratically (in the case of one-dimensional quantum walk) with the number of time steps that one wants to obtain.

Here, I propose a novel approach that is actually halfway between the two schemes described above. By means of this, it is possible to realize a quantum walk with optical loops in an integrated waveguide circuit, also avoiding the problem given by the fact that polarizing beam splitters are hard to be implemented in these particular setups. The number of elements, as in the first approach, is fixed regardless of the number of time steps that one wants to obtain. I will discuss the details of the new scheme, describing how the model can be modified to include the possibility of increasing the dimension of the lattice on which the walker is moving, as well as having control over the different parameters involved in the evolution. I will finally mention the preliminary results obtained with this approach by the experimental group of Prof. Walmsley at the University of Oxford.

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