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Linear Optical Quantum Computing in a Single Spatial Mode[1]

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We present a scheme for linear optical quantum computing using time-bin encoded qubits in a single spatial mode. This scheme allows arbitrary numbers of qubits to be encoded in the same mode, circumventing the requirement for many spatial modes that challenges the scalability of other schemes, and exploiting the inherent stability and robustness of time-frequency optical modes. This approach leverages the architecture of modern telecommunications systems, and opens a door to very high dimensional Hilbert spaces while maintaining compact device designs. Further, temporal encodings benefit from intrinsic robustness to inhomogeneities in transmission mediums. These advantages have been recognized in works exploring the preparation of time-frequency entangled states both for tests of fundamental quantum phenomena, and for quantum communications technologies including key distribution and teleportation. Here we extend this idea to computation. In particular, we present methods for single-qubit operations and heralded controlled phase (CPhase) gates, providing a sufficient set of operations for universal quantum computing with the Knill-Laflamme-Milburn scheme. As a test of our scheme, we demonstrate the first entirely single spatial mode implementation of a two-qubit quantum gate and show its operation with an average fidelity of 0.84 /pm 0.07. An analysis of the performance of current technologies suggests that our scheme offers a promising route for the construction of quantum circuits beyond the few-qubit level. In addition, we foresee that our investigation may motivate further development of the approaches presented into a regime in which time bins are temporally overlapped and frequency based manipulations become necessary, opening up encodings of even higher densities.

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