Experimental implementation of optimal linear-optical controlled-unitary gates

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Experimental implementation – We have constructed an experimental setup as depicted in Fig. 1. It consists of a tunable c-phase gate placed between single-qubit gates in the signal mode that implement required unconditional rotations. In our experiment we encode qubits into polarization states of individual photons (|0⟩ corresponds to horizontal polarization |H⟩, |1⟩ to vertical polarization |V⟩). Unconditional single-qubit rotations are implemented by sets of one half- and one quarter-wave plates. The control state preparation is achieved by one half-wave plate in control mode since only logical states |0⟩ and |1⟩ are required. Photons were generated using Type I spontaneous parametric down-conversion in a LiIO3 crystal pumped by 200 mW cw Kr+ laser beam. The observed coincidence rate was ranging approximately from 300 to 3000 counts per second depending on the success probability given for various settings of $\varphi$. By following the procedure described in Ref. [5], we have adjusted the tunable c-phase gate to a given phase shift $\varphi$.

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In this contribution we show that using a tunable c-phase gate instead of a CNOT gate makes it possible to (i) reduce the complexity of various quantum circuits and (ii) increase the success probability of these circuits in linear optics [1]. The support for our idea comes from an experimental implementation of the proposed scheme.

Arbitrary single-qubit controlled-unitary transformation – It has been shown by Barenco et al. [2] that two controlled-sign gates are needed to implement an arbitrary controlled-unitary operation acting on a single qubit and controlled by a control qubit. In special cases, one controlled-sign gate is sufficient, but at the expense of restricting the class of implemented operations. Considering the probabilistic nature of controlled-sign gates on the platform of linear optics, it is crucial to limit their repetition as much as possible. We show that only one single tunable controlled-phase gate is needed for the construction of a universal single-qubit controlled-unitary operation. Note, that the success probability of two consecutive controlled-sign gates would be 1/81 (using linear optics only and no photon ancillae), the minimum success probability of a tunable controlled-phase gate is 1/11 (0.14 on average). Moreover, by reducing the number of gates from two to one, we also avoid the need for intermediary non-demolition presence detection otherwise required to join two probabilistic gates [3][4].

FIG. 1. (color online) Schematic drawing of the experimental setup. The components are labeled as follows: MT – motorized translation, HWP – half-wave plate, QWP – quarter-wave plate, PBS – polarizing beam splitter, BDA – beam divider assembly, BD – beam divider, D – detector.

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