Experimental implementation of optimal linear-optical controlled-unitary gates

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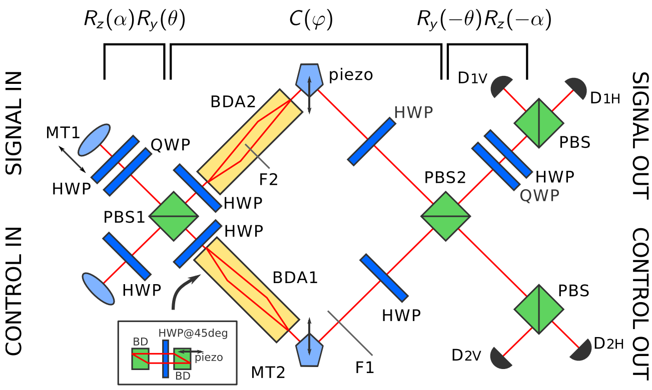

FIG. 1. (color online) Schematic drawing of the experimental setup. The components are labeled as follows: MT – motorized translation, HWP – half-wave plate, QWP – quarter-wave plate, PBS – polarizing beam splitter, BDA – beam divider assembly, BD – beam divider, D – detector.

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 signal 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].

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 ($|0\rangle$ corresponds to horizontal polarization $|H\rangle$, $|1\rangle$ to vertical polarization $|V\rangle$). 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 $|0\rangle$ and $|1\rangle$ are required. Photons were generated using Type I spontaneous parametric down-conversion in a $LiIO_3$ 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 φ. By following the procedure described in Ref. [5], we have adjusted the tunable c-phase gate to a given phase shift φ.

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