Optimization of Quantum Entangling Protocols for Systems of Neutral Atoms in Optical Microtraps

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Systems of laser-cooled atoms, confined in dipole microtraps or optical tweezers are an attractive experimental platform for large-scale quantum information processing systems, which demonstrate high potential for scalability and can support up to hundreds of qubits in a single array. Here we present the analysis and optimization of various physical parameters of atomic entangling gates based on the Rydberg blockade — a cornerstone technique in quantum computing with neutral atoms. Using a realistic physical model of the full multilevel Zeeman structure of interacting Rydberg atoms, we estimate the blockade shift dependence on the inter-atomic distance and the angle between the inter-atomic axis and the polarization of the driving field aiming to find a configuration providing optimal fidelity for the controlled-phase protocol for the two-qubit CZ gate originally proposed in [1].

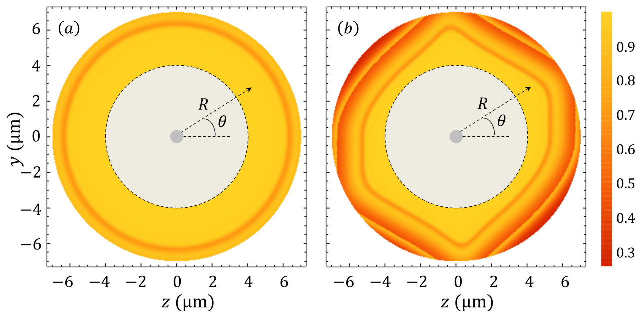

Figure 1: CZ-gate fidelity $F = F(R, \theta)$ as a function of spatial and angular schemes parameters $z = R\cos\theta$, $x = R\sin\theta$ for the excitation via Rydberg state $|70s(^2S_{1/2})\rangle$ (left panel) and $|70d(^2D_{3/2})\rangle$ (right panel). The shaded area corresponds to relatively short distances of several microns, where the interatomic potential deviates from scaling $\propto R^{-6}$

We present the results of our numerical simulations for the fidelity of the prepared entangled state of two qubits. The observed non-trivial dependence of fidelity on the effective Rabi frequency $|\Omega|$ and the Rydberg shift δ_R suggests that the effective Rabi frequency can be considered as an adjustable parameter for gate performance optimization with respect to spatial coordinates, see [2] for more details.

We analyze and compare the cases of different experimentally accessible excitation geometries searching for an experimental configuration optimizing the entanglement preparation. Density plots in Figs. 1(a) and 1(b) visualize the calculated fidelity of two spatial arguments $F = F(R, \theta)$ for the two considered excitation schemes via Rydberg state $|70s(^2S_{1/2})\rangle$ (left panel) and $|70d(^2D_{3/2})\rangle$. Our methods and results may find implementation in numerical models for simulation and optimization of neutral atom-based quantum processors, the strong angular dependence, which arises for the case of excitation via $|70d(^2D_{3/2})\rangle$ may provide a useful tool for selective addressing of atoms in the qubit array.

The obtained results show that fidelities at the level of 99% are in principle achievable and highlight the possibility of gate fidelity further optimization via variation of different gate parameters, not only the amplitude but also the phase of complex effective Rabi frequency. As we expect, the problem of choosing the best, or optimum, solution for the "program of control" $\Omega(t) = |\Omega(t)|e^{i\phi(t)}$ can be considered in terms of the variational approach based on sufficient conditions for global optimality of control processes [3].

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References

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