Fast spin-dependent transport of neutral atoms using quantum optimal control

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We report on the experimental demonstration of fast, high-fidelity transport of single atoms in spin-dependent optical lattices. Employing a fast polarization synthesizer [1] enables the independent control of the spin-dependent lattice potentials with angstrom precision and allows reaching transport times down to the harmonic oscillator period of the order of $10\,\mu s$ over one lattice site ($\approx 0.5\,\mu m$). These transport sequences, which are extracted from quantum optimal control theory applied to a numerical quantum simulation, are believed to reach the fundamental speed limit of our quantum system. While the identified transport operations close to the quantum speed limit are strongly non-adiabatic and excite the atoms by several motional quanta, they refocus the wavefunction back to the ground state at the end of the transport with high fidelity. This is experimentally confirmed by measuring the excitation spectrum of the transported atoms by a custom microwave sideband spectroscopy. The fast, high-fidelity state-dependent transport operations are planed to drive discrete time quantum walk protocols providing a versatile platform to simulate artificial matter like topological insulators.

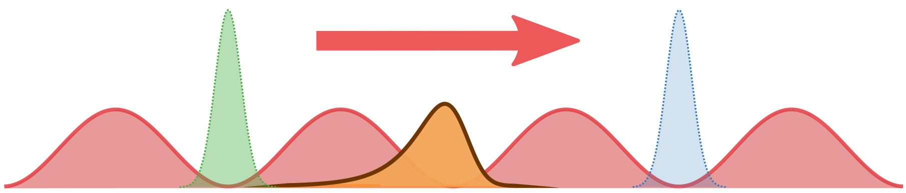

FIG. 1: Sketch of the atomic wave function during an optimal control transport sequence connecting two motional ground states.

[1] C. Robens, S. Brakhane, W. Alt, D. Meschede, J. Zopes and A. Alberti, "Fast, High-Precision Optical Polarization Synthesizer for Ultracold-Atom Experiments," Phys. Rev. Appl **9**, 034016 (2018)