Optimal control of a Bose-Einstein condensate in an optical lattice

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The ever-increasing degree of control in cold atoms experiments has allowed the field to thrive in recent years, in particular as a platform for quantum simulation. Key requirements for quantum simulation are the ability to prepare relevant initial states, engineer model dynamics, and measure the results. The time-modulation of experimental parameters is a very fruitful way to engineer specific dynamics or to improve the preparation of quantum states. To achieve these goals with high accuracy, one can take advantage of optimization techniques, such as optimal control.
I will present our results on applying quantum optimal control to shape the quantum state of Bose-Einstein condensates in a one-dimensional optical lattice. Through an optimised modulation of the lattice position, we can tailor the collective wavefunction of the condensate [1]. Using this tool, we can prepare a variety of translated and squeezed Gaussian states, and superpositions of Gaussian states. Complete reconstruction of the state is performed through a maximum likelihood state tomography, demonstrating an efficient preparation [2]. We thus achieve the preparation of states inaccessible using adiabatic methods. We also investigated how optimal control can stabilize the prepared states stroboscopically, highlighting the existence of a quantum speed limit.

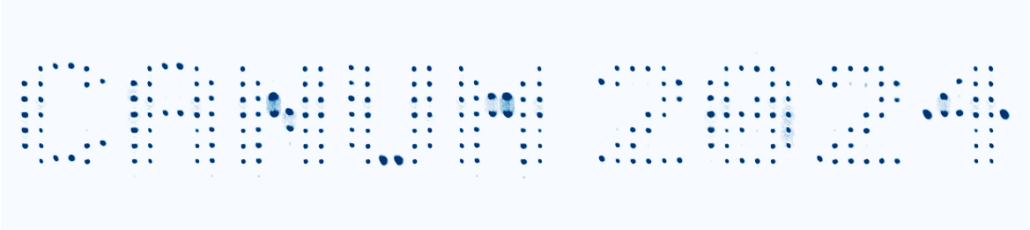

FIGURE 1 – **BEC "printer"** : each of the columns of this image is a single measurement (absorption image) of the momentum distribution of a Bose-Einstein condensate (BEC) in an optical lattice, taken after optimal preparation of an equal-weight momentum superposition of momen- tum states from -3 to +3 lattice momentum units.

[1] N. Dupont, G. Chatelain, L. Gabardos, M. Arnal, J. Billy, B. Peaudecerf, D. Sugny, D. Guéry-Odelin. *Quantum State Control of a Bose-Einstein Condensate in an Optical Lattice.* PRX Quantum, **2**, 040303, 2021.

[2] N. Dupont, F. Arrouas, L. Gabardos, N. Ombredane, J. Billy, B. Peaudecerf, D. Sugny, D. Guéry-Odelin. *Phase-space distributions of Bose–Einstein condensates in an optical lattice : optimal shaping and reconstruction.* New Journal of Physics, **25**, 013012, 2023.

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