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Single-atom-resolved probing of lattice gases in momentum space

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Correlations between the degrees of freedom of individual quantum particles has been identified as a key resource to solve open many-body problems. So far, a large experimental effort has been devoted to the building of apparatus capable of measuring spatial and spin correlations in one and two dimensions. We will present an experiment that provides access to multi-particle correlations between the momentum degree of freedom in three-dimensional lattice systems. We produce Bose-Einstein condensates of Helium-4 atoms in a metastable state [1,2], whose internal energy (19.6 eV) is large enough to allow for an electronic detection of individual atoms in three dimensions [3,4]. Thanks to the light mass of Helium-4 and to a long time-of-flight of 330 ms, we probe the gas in the far-field regime of expansion where the atom distribution can be exactly mapped on the in-trap momentum distribution. Comparison with ab-initio Quantum-Monte Carlo calculations in the Bose-Hubbard regime qualifies our apparatus as a single-atom probe delivering momentum distributions of strongly interacting systems as large as $60 \times 60 \times 60$ sites [5]. This provides for the first time access to physical quantities of interest, like the condensed fraction and momentum correlations, which are central to phase transitions.

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