Atom-chip-based generation of entanglement for quantum metrology

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Atom chips provide a versatile quantum laboratory for experiments with ultracold atomic gases. They have been used in diverse experiments involving low-dimensional quantum gases, cavity quantum electrodynamics, atom–surface interactions and chip-based atomic clocks and interferometers. However, a severe limitation of atom chips is that techniques to control atomic interactions and to generate entanglement have not been experimentally available so far. Such techniques enable chip-based studies of entangled many-body systems and are a key prerequisite for atom chip applications in quantum simulations, quantum information processing and quantum metrology11. Here we report the experimental generation of multi-particle entanglement on an atom chip by controlling elastic collisional interactions with a state-dependent potential. We use this technique to generate spin-squeezed states of a two-component Bose–Einstein condensate; such states are a useful resource for quantum metrology. The observed reduction in spin noise of -3.7 ś 0.4, combined with the spin coherence, implies four-partite entanglement between the condensate atoms; this could be used to improve an interferometric measurement by -2.5 ś 0.6over the standard quantum limit. Our data show good agreement with a dynamical multi-mode simulation and allow us to reconstruct the Wigner function of the spin-squeezed condensate. The techniques reported here could be directly applied to chip-based atomic clocks, currently under development.
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