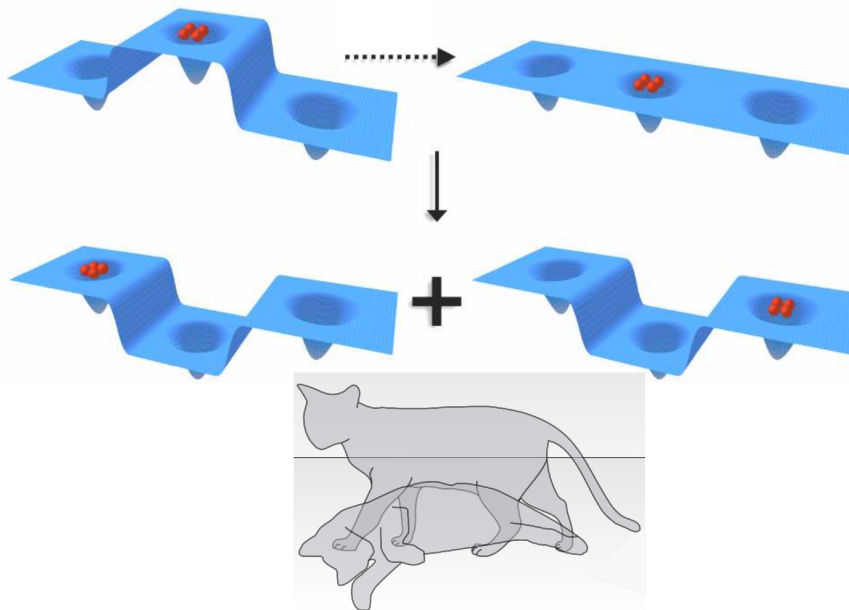




Creating highly entangled NOON states with ultracold bosonic atoms

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NOON states, given by a coherent superposition of the form $|N,0\rangle + |0,N\rangle$ (possibly amended by relative phase factors), are highly entangled quantum states that involve N bosonic quanta on two modes. They can be seen as manifestations of Schrödinger cat states and are of great potential interest for quantum metrology, especially when being realized with matter. Here we discuss viable proposals for the creation of such NOON states using ultracold bosonic atoms that are located on two symmetric sites of a lattice. The protocols that we focus on are based on collective tunneling, taking place in the self-trapping regime where on-site interaction is dominant with respect to inter-site hopping. While the associated collective tunneling rate is prohibitively slow for realistic lattice parameters, we show that it can be drastically enhanced via a periodic driving of the configuration, giving rise to chaos-assisted tunneling [1]. Further reductions of the NOON state creation time are possible through adiabatic transitions into the NOON superposition, whose efficiency can be substantially enhanced via the technique of counterdiabatic driving [2]. NOON states with $N = 5$ particles can then be created on time scales significantly below a second, which is in reach within ultracold atomic setups. We also discuss the generalization of the NOON state concept to more than two modes, whose generation is equally feasible with the above approaches.

[1] G. Vanhale and P. Schlagheck, PRA 103, 013315 (2021); G. Vanhale et al., PRA 106, L011301 (2022).

[2] S. Dengis, S. Wimberger, and P. Schlagheck, PRA 111, L031301 (2025).