Spatial mesoscopic quantum superpositions generated via scattering of bright solitons

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We investigate the scattering of a quantum matter wave soliton on a barrier in a one-dimensional geometry via a mathematically justified effective potential approach. We show that it can lead to mesoscopic quantum superposition states, where the atomic gas is in a coherent superposition of being in the half-space to the left of the barrier and being in the half-space to the right of the barrier. We propose an interferometric method to reveal the coherent nature of this superposition, and we discuss the experimental feasibility. Recent results on applications of the effective potential are also presented.

FIG. 1: Rather than producing a cat which is in a superposition of alive and dead, the aim of this theoretical proposal is to prepare a quantum matter wave soliton of some 100 atoms in a spatial quantum superposition of being in the right and left of a barrier.

This idea can be treated analytically on the $N$-particle level by combining the Lieb-Liniger model with attractive interaction and an effective potential approach [1]. The mathematically justified [1] effective potential approach was tested numerically for two interacting particles [2], for numeric investigations on the $N$-particle level see Ref. [3]. As an experimental signature of the mesoscopic quantum superposition we suggest to use interference fringes of the center of mass coordinate. To achieve such a spatial quantum superposition of some hundred atoms is a challenge of fundamental research.

Motivated by recent experiment in the group of Prof. R. G. Hulet [4], we also investigate bright solitons in one-dimensional harmonic trapping potentials [5].

FIG. 2: The left panel demonstrates the improvement of the exact numerics if the center or mass approximation $V(x_1) + V(x_2) \approx 2V[(x_1 + x_2)/2]$ is replaced by the effective potential [2]. The right panel demonstrates how the interference patterns of the center of mass coordinate could be detected via fluorescence imaging [1].