Momentum correlations of a few ultracold bosons escaping from an open well

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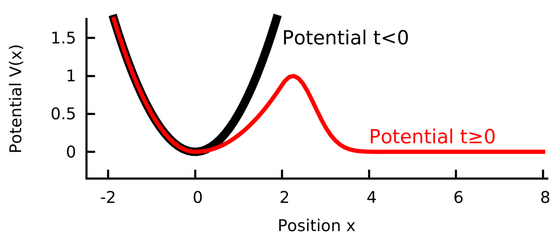
Abstract

The dynamical properties of a one-dimensional system of two and three bosons escaping from an open potential well are studied in terms of the momentum distributions of particles. In the case of a two-boson system, it is shown that the single- and two-particle momentum distributions undergo a specific transition as the interaction strength is tuned through the point where tunneling switches from the pair tunneling to the sequential one. Characteristic features in the momentum spectra can be used to quantitatively determine the participation of specific decay processes. A corresponding analysis is also performed for the three-boson system, showing a scheme for generalizations to higher particle numbers. The results provide insight into the dynamics of decaying few-body systems and offer potential interest for experimental research.

The model

$$H = \sum_i \left[-\frac{\hbar^2}{2m} \frac{\partial^2}{\partial {x_i}^2} + V(x_i) \right] + g \sum_{i<j} \delta(x_i - x_j)$$

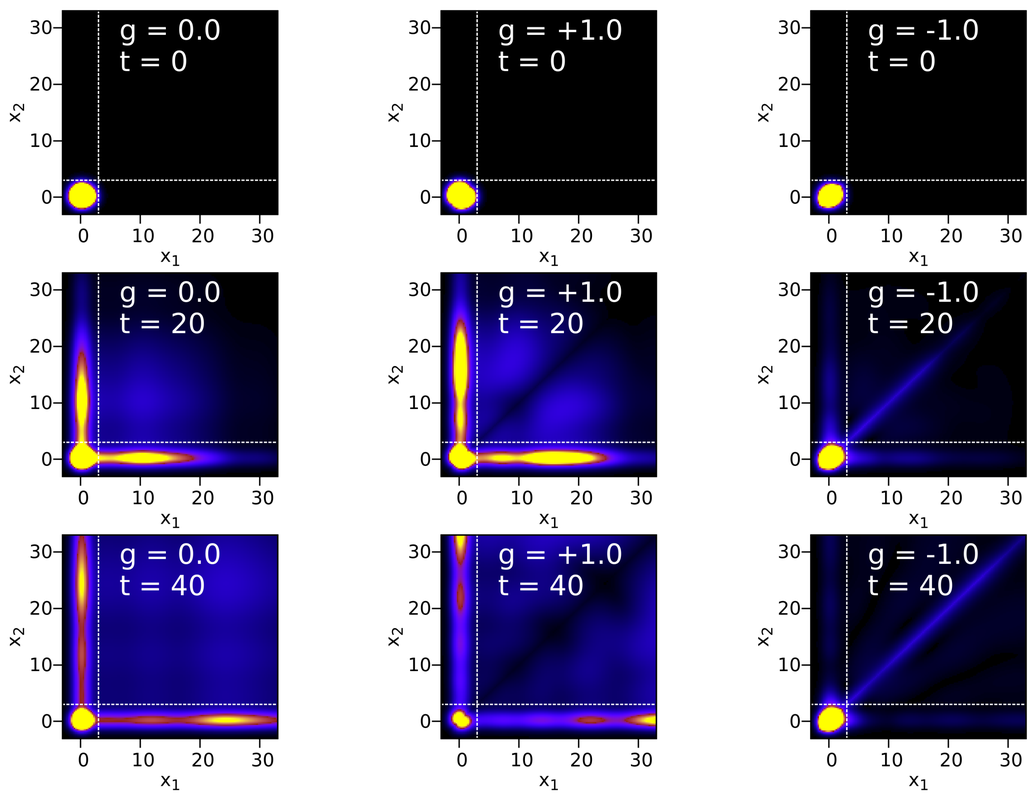


The setup: Initial state is the harmonic oscillator ground state of N interacting bosons

At $t = 0$ the trap is suddenly opened and the particles can tunnel into open space

Two-boson dynamics

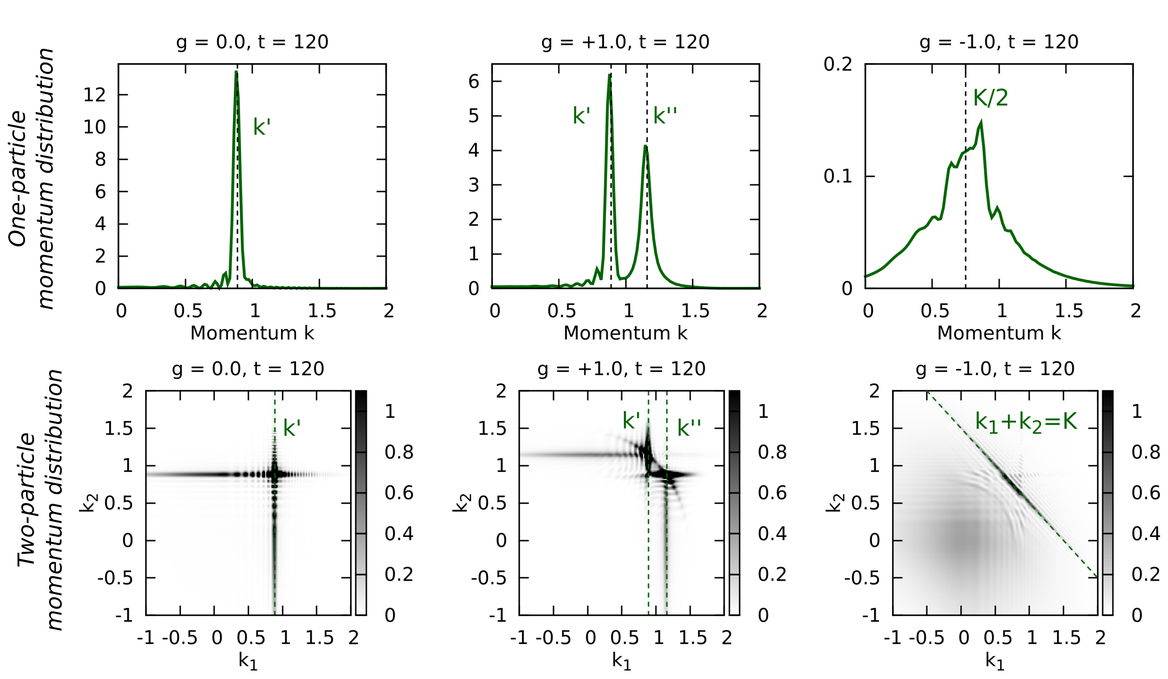
Probability density: Probability of finding the two bosons at positions x_1, x_2 at time t



Depending on g, the dominant tunneling mechanism is different: bosons tunnel one by one (sequentially), or in pairs

Momentum distribution: Probability to find bosons with given momenta in the decayed system

The momentum distributions of the escaped particles can serve as a footprint for identifying the dominant tunneling mechanism



Non-interacting system: both bosons tunnel with the same momentum k'

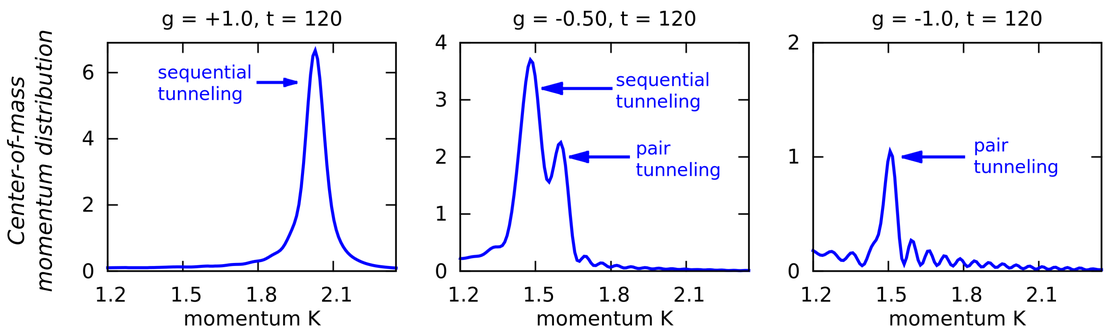
Repulsive system: bosons tunnel sequentially, with different momenta k', k''

Attractive system: bosons tunnel as a pair, with the center-of-mass momentum K

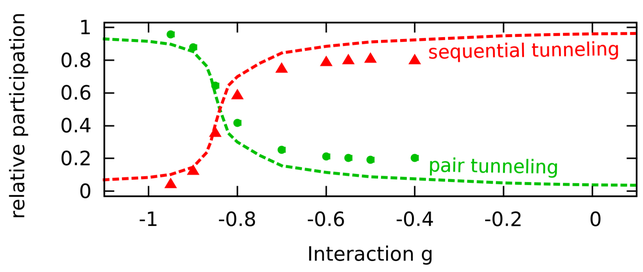
Center-of-mass momentum

Center-of-mass momentum distribution: Probability that the two-boson system has a given center-of-mass momentum $k_1 + k_2 = K$

Depending on whether the two bosons tunnel sequentially or as a pair, their center-of-mass momentum will be different — peaks in the distribution can be associated with different tunneling mechanisms



By comparing the areas under the peaks, we can directly calculate the relative probability of sequential vs. pair tunneling

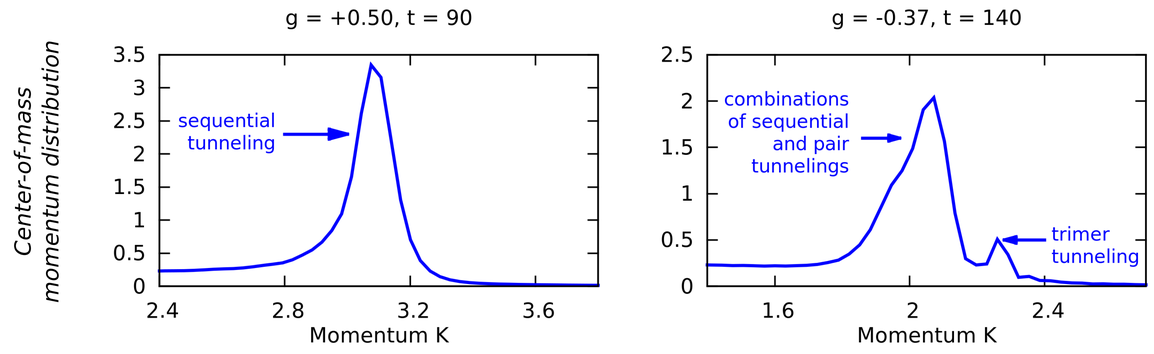


For comparison we also show earlier theoretical results [Phys. Rev. A **98**, 013634 (2018)], obtained by a direct analysis of probability fluxes through the potential barrier

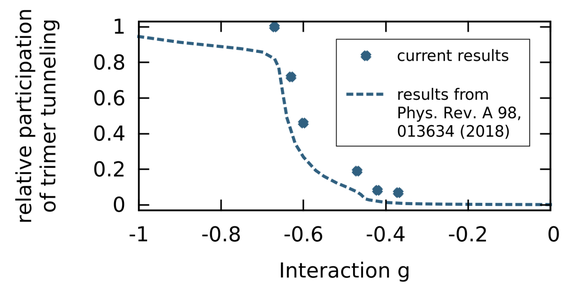
Current results *Results from Phys. Rev. A **98**, 013634 (2018)*

Extension to higher particle numbers

Three-boson case: For N=3 bosons, more tunneling mechanisms are possible: bosons can tunnel as single particles, pairs, or trimers. This is reflected in the center-of-mass momentum distribution



By calculating the area under the corresponding peak, we can obtain the relative participation of trimer tunneling



Summary

- The momentum distributions of the decaying N-boson system offer a way to distinguish between different regimes, characterized by the dominance of different decay processes
- The center-of-mass momentum distributions offer a way to experimentally quantify the participation of different decay processes
- The approach can be extended to higher particle numbers N>2

More details:

Phys. Rev. A **99**, 063608 (2019)