# Quantum dynamics of ultracold atoms in double wells

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Ultracold atoms in a double-well are one of the simplest systems in which to probe quantum many-body physics. Nevertheless, the system contains some very rich physics, including quantum coherence, Josephson effects, localisation, squeezing and entanglement. Furthermore, as it has the basic form of an interferometer, the double well is an important system for possible precision measurement with ultracold atoms. Here we summarize four different projects that are investigating quantum dynamics of bosons and fermions in a double-well potential.

The first two projects explore the behaviour of small condensates in a double-well potential, using a two-mode approximation and a number state analysis. For the case of repulsive interactions, the squeezed ground state has been suggested to achieve precision measurement beyond the standard quantum limit [?]. We have investigated the nonlinear effects of residual interactions during the course of the measurement, finding that they do have a detrimental effect on the precision. We have also proposed and tested schemes to overcome these nonlinear effects over a range of interaction strengths. For the case of attractive interactions in double-well condensate, it may be possible to dynamically create a macroscopic superposition state by making use of the Feshbach resonance. We have considered various measurements aimed at distinguishing a superposition state from a statistical mixture, including quadrature phase measurements and atom number measurements after a short tunelling time. We have found that both these sets of measurements would require very accurate atom counting to successfully distinguish between a coherent superposition and a statistical mixture of states. For the quadrature phase measurements, successfully detecting a superposition state may increase in difficulty with the number of atoms involved in the state, due to a narrowing of the expected interference fringes. In the third project, we go beyond the two-mode model, using a fully 3D spatial Bogoliubov approach to the two well systems, to analyse the number squeezing and compare it to experiments at Heidelberg [?].

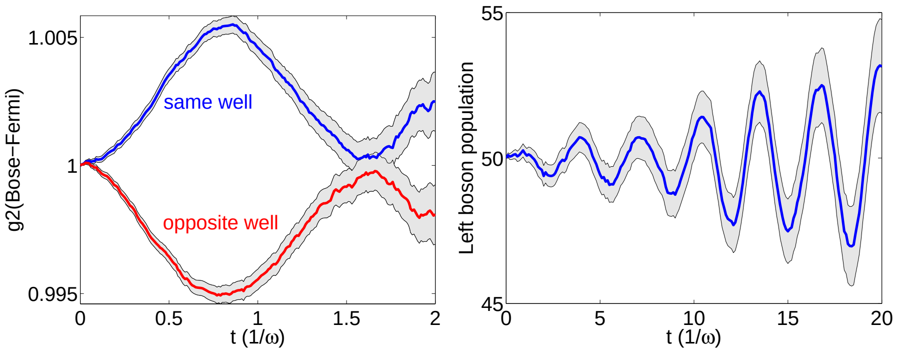


Fig. 1: Dynamics of Bose-Fermi mixtures in a double-well potential. Left: nonclassical correlations develop as a result of Bose-Fermi repulsion. Right: fermion imbalance causes oscillations to develop in Boson population.

Finally, we have used the double-well system to test novel phase-space simulation methods for the quantum dynamics of fermions. The simulation methods are based on a generalised Gaussian representation of the quantum density matrix and have previously been used to calculate the ground-state properties of the repulsive Hubbard model. Here we focus on real-time quantum dynamics, and Bose-Fermi mixture in particular. Preliminary work shows that the Gaussian method is able to simulate tunnelling dynamics in situations where significant beyond-mean-field correlations develop.

## References

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