Noise Correlations, Counting Statistics & Spin Dynamics of Ultracold Atoms in Optical Lattices

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Neutral atoms in optical lattice offer powerful possibilities for the simulation of fundamental many-body Hamiltonians. In order to reveal many of the highly correlated quantum states, probes sensitive to higher order correlation functions are required, which go beyond simple absorption or dispersive imaging techniques. As an example, novel detection techniques based on Hanbury Brown & Twiss type quantum noise correlations in expanding ultracold atom clouds will be presented and applications for the read-out of novel quantum many body phases of a neutral atom based quantum simulator will be discussed. Furthermore, it will be shown how resonant control over spin changing collisions in optical lattices allows a non-destructive measurement of the atom number statistics, similar to measurements of the photon number statistics in Cavity QED. Employing such spin changing collisions it has become possible to reveal the fundamental change in atom number statistics across the superfluid to Mott insulator transition and directly detect the emergence of highly squeezed number states together with the shell structure of a Mott insulator in a harmonic lattice potential.