Generation of long-range entanglement in a macroscopic spin singlet

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We report the generation of long-range entanglement in a macroscopic spin singlet (MSS) [1,2] via collective quantum non-demolition (QND) measurement [3] a global entanglement method predicted [4] to produce entanglement at all length scales. In a cold ^{87}Rb spin ensemble of up to 2×10^6 atoms, we generate a MSS, entangling at least half of the atoms. Using a gradient field to convert singlets to triplets, we detect the decay of entanglement in the MSS via spin noise spectroscopy [4] consistent with a mean entanglement length comparable to the size of the atom cloud ($\sim$ 4mm), three orders of magnitude larger than previously detected in atomic spin systems [5].

Long-range entanglement is central to outstanding problems in condensed matter physics, including high-T_c superconductors and the quantum Hall effects [6,7]. The study of such models is a major goal of atomic quantum simulation [8] and many essential capabilities have been developed, however generating long-range entanglement by local interactions is challenging [9] and to date only short-range (μm) entanglement has been shown [5]. The QND technique offers a promising new route to large-scale entanglement generation and detection for quantum simulation [10,11].

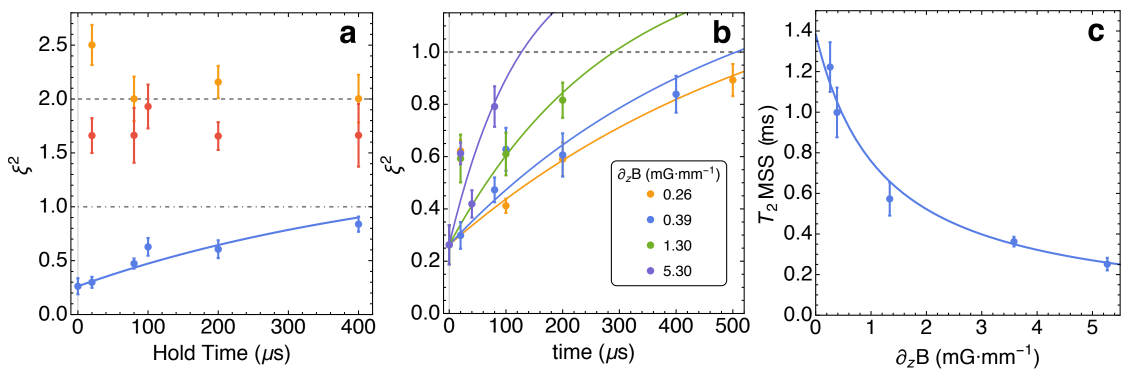

Fig. 1 Noise spectroscopy of a MSS via QND measurements of the spin squeezing parameter ξ^2 after a variable hold time in an applied gradient field. (a) The MSS (blue) rapidly dephases due to singlet-triplet spin flips [4], where as the detection spin noise from a reference thermal spin state (TSS) [12] measured before (yellow) and after (red) applying the field gradient remains constant. (b) The spin dephasing rate can be altered by changing the magnitude of the applied field gradient. (c) Measured dephasing time of the MSS as a function of the applied field gradient. A simple model fitted to the data (solid curve) indicates a mean entanglement length comparable to the size of the atom cloud ($\sim$ 4mm)

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978-1-4673-7475-0/15/$31.00 ©2015 IEEE