

Generation of a macroscopic spin singlet

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Generating and detecting highly entangled macroscopic singlet states is of enormous interest. Such states are the ground states of many fundamental spin models (e.g. the anti-ferromagnetic Heisenberg model) [1], and may be useful for quantum information [2] and quantum metrology [3] applications. An ideal singlet has total angular momentum with zero mean and zero variance, a truly zero angular momentum. Approximate singlets can be identified with a generalized spin squeezing inequality (SSI) for unpolarized states [4], which show that total spin variance below a standard quantum limit (SQL) implies entanglement among the spins. We generate approximate singlet states using the tools of measurement-induced spin squeezing: quantum non-demolition measurement [5] and coherent magnetic rotations [6]. By squeezing all three spin components, we approach the zero of total spin. Using a cold rubidium atomic ensemble and near-resonant Faraday rotation probing, we have observed up to 3 dB of squeezing relative to the SQL, and a violation of the SSI by more than 5 standard deviations [7].

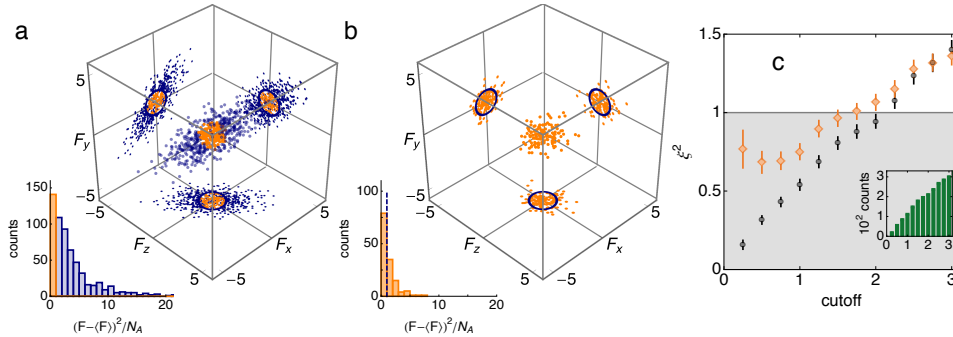


Figure 1: From the initial spin distribution (blue data in figure (a)), we select data with $|\mathbf{F}^{(1)} - \langle \mathbf{F}^{(1)} \rangle|^2/N_A < C$ (orange data in figure (a)), where C is a chosen cutoff parameter. We then analyze the second QND measurement $\mathbf{F}^{(2)}$ of the selected data (figure(b)) to detect spin squeezing and entanglement. We illustrate this with data from a sample with $N_A = 1.1 \times 10^6$ atoms and $C = 1$. Axes in (a) & (b) have units of 10^3 spins. Solid blue circles (a) and (b) have a radius $\sqrt{CN_A}$. In the insets we plot a histogram of the first and second measurements. The selected data are plotted in orange, and the dashed blue line in (b) indicates the cutoff. (c) Spin squeezing parameter ξ^2 (orange diamonds) calculated from the second QND measurement of the selected data as a function of the cutoff parameter C . For reference, the same parameter calculated from the first QND measurement is also plotted (black circles). Inset: number of selected data points included as a function of the cutoff parameter.

References

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