Generation of a macroscopic singlet state in an atomic ensemble

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We report on an experiment underway for generating a singlet state in a cold atomic ensemble. The experiment is based on a recent proposal to generate these states by applying a quantum non-demolition (QND) measurement and feedback to an unpolarized ensemble [1]. Our criteria for generating the singlet state is the spin squeezing parameter

$$\xi_s = \frac{(\Delta F_x)^2 + (\Delta F_y)^2 + (\Delta F_z)^2}{Nf} \quad (1)$$

where F_i are the components of the collective angular momentum, N is the number of atoms and f is the spin of a single particle. Any state with $\xi_s < 1$ is an entangled state [2]. Our procedure, described bellow, will lead to a highly entangled state with $\xi_s \ll 1$ starting from a non-entangled state with $\xi_s \sim 1$.

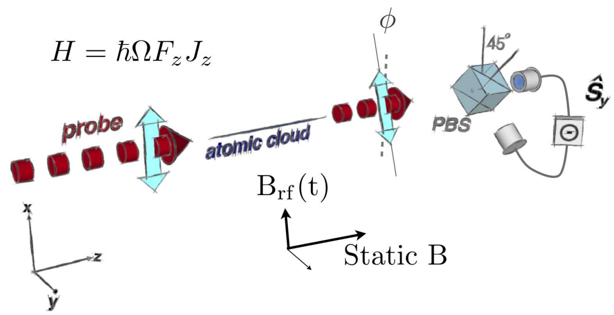

Fig. 1: Schematic of the experiment: The experimental apparatus is an optical dipole trap which is able to trap about one million ^{87}Rb atoms at temperature of about $25\mu K$. The geometry of dipole beam provides for co-propagating probe beam of a large atom-light interaction with an effective on-resonance optical depth above 50 [3]. Omnidirectional optical pumping prepares a completely mixed state in cold atomic ensemble, which is the same as direction as 3D MOT cooling beam in three counter-propagating direction. Magnetic field in the set up is controlled using 3 Helmholtz coils.

The starting point of the experiment is the preparation of a completely mixed spin state in an ensemble of about 10^6 cold ^{87}Rb atoms via omnidirectional optical pumping. It is the most similar classical state to the quantum state that we want to produce. Applying QND measurement to this state reduces the fluctuations of the collective angular momentum component variance ΔF_z. We apply the QND measurement using a detuned pulses of light from $5S_{1/2} \rightarrow 5p_{3/2}$ D_2 line transition of ^{87}Rb to measure the collective angular momentum component $\mathbf{F}$ of an ensemble of about one million cold ^{87}Rb atoms [4]. To generate the singlet state, the measurement outcome $z = S_y^{in} + \kappa F_z^{in}$ is fedback into the atomic variable F_z. We have simulated an optical feedback procedure and we demonstrated that feedback in the form of optical pumping and relaxation is a good feedback candidate, with a negligible amount of noise produced during the process of restoring $\langle F_l \rangle = 0$. In order to be able to do feedback in appropriate way, real time measurement capability is necessary. We have developed a new detection system which is shot noise limited and provides integrated pulse measurement in real time. This detection system gives us the signal that we can use in real time to do feedback optical pumping.This will able us to produce progressively closer approximation to an ideal macroscopic singlet state.

References

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