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QIBEC
Quantum Interferometry with Bose-Einstein Condensates
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D4.1
Schemes and performances of optimized atom detectors

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Table of contents

Summary

Deliverable 4.1 consists in the development and performance testing of atom detection schemes. As envisaged in the proposal, several partners obtained results in this respect. The CNRS node developed a surprisingly accurate method of QND atom counting in an optical cavity, which played a key role in the cavity-based entanglement production described in D2.2. TU-WIEN originally planned to tackle the problem of high-efficiency atom counting by improving its fluorescence atom detector. During the implementation of their trapped-atom interferometer it turned out that the efficiency of their currently available atom detector is sufficient for the planned experiment. Therefore TU-WIEN focused on the implementation and the demonstration of the number-squeezing enhanced performances of their trapped-atom interferometer (WP3). UHEI realized a new atom detector based on fluorescence detection in a small magneto-optical trap, which allows a state-selective detection of one particle in 10^3.

Since it turned out that the impressive detector developed at CNRS and TU-WIEN are not immediately applicable to the setup at UHEI, the Heidelberg group realized a new atom detector based on fluorescence detection in a small magneto-optical trap, which allows a state-selective detection of one particle in 10^3.

The experimental unit at CNR performed tests on their imaging system, demonstrating their capability of measuring the atom number in at least 20 interferometers at the same time. In view of the challenges inherent in the task, CNR decided to defer the development of detection schemes sensitive to the difference in atom number between the output ports of the interferometer, and to forward those independently counting the atoms in the two modes. The theory team at CNR has developed a protocol to include finite detection efficiency to the calculation of the Fisher information.

Detailed descriptions of the results of the partner nodes.

CNRS

As planned in the proposal, we have developed a method of QND atom counting where the dispersive shift of nonresonant atoms in a detuned cavity changes the transmission of a probe beam. We have shown that this method is surprisingly precise, achieving an atom number accuracy below 2 in the relevant range between 10 and 40 atoms that was explored in the experiment. This method is used successfully as part of the cavity-based entanglement production described in the results of WP2.

UHEI

In the work package 4 the consortium will develop new detectors for the improved readout. Since it turned out that the impressive detector developed in the CNRS node is not immediately applicable to the setup in the Heidelberg node. Therefore a much simpler scheme for particle number detections has been realized in Heidelberg allowing counting up to 1000 particles one by one. This detector relies on the fluorescence detection in a small magneto optical trap. The performance of state selective detection employing this method gives experimentally determined errors of 10^{-3} i.e. one particle for a cloud of 1000 particles.

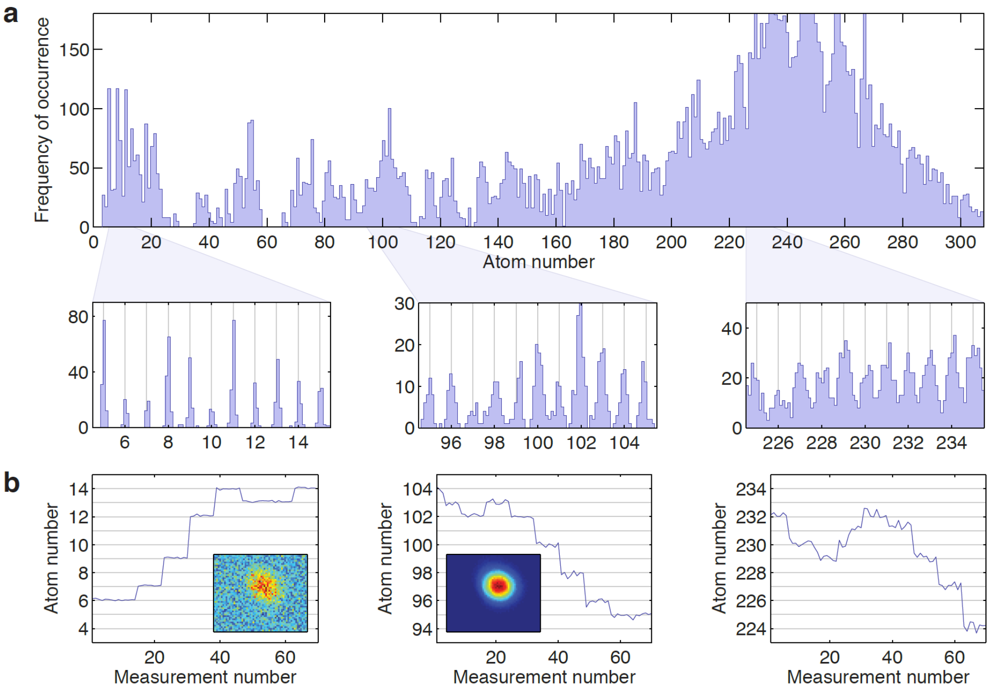

Figure 1 single particle detection up to 1000 particles.

CNR

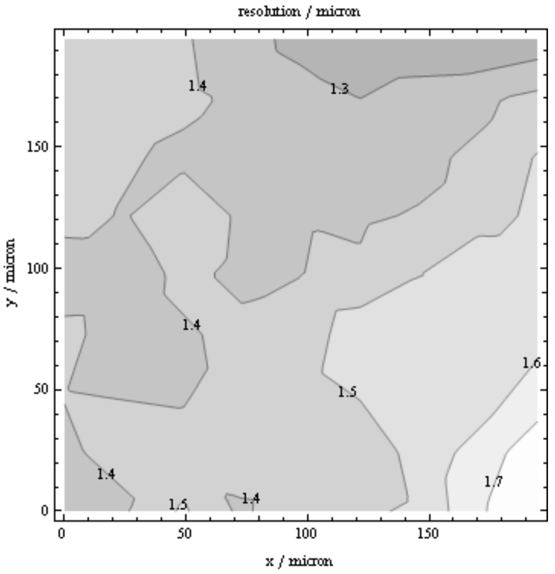

Figure 2 Spatial resolution of our imaging system at different positions, moving orthogonally to the imaging axis. Considering that our super-lattice potential is made of one double well every 10 microns we can achieve enough spatial resolution for the atom counting of at least 20 interferometers at the same time.

Concerning the atom-detection techniques we have worked on the operation of a five lenses infinite conjugated objective with a numerical aperture of 0.55 and a working distance of 17 mm. Tests on its performance using an additional telephoto objective (total magnification of 40) have shown a resolution at best of 1.3 microns imaging the florescence of 100 nm nanoparticles placed between two thin glass plates. Although this value is more than sufficient for our measurement purposes (the separation between the two wells is 5 micron) it is slightly larger than the theoretical diffraction limit. This might be due to non-perfect assembly of the objective lenses or interference effects arising from unwanted reflections on the glass plates. Finally we have tested the field of view of our imaging system. Results are shown in Figure 2. The results clearly demonstrate our possibility to measure the atom number in the two wells of several double well potential at the same time (at least 20 interferometers).

We have characterized the experimental measurement of the Fisher information by taking into account the contribution of detection noise. This is the main source of noise in several phase estimation experiments. This is obtained by a convolution of the ideal conditional detection probabilities $P_{id}(\mu|\theta)$, where μ is the possible result of a measurement, with a noise model given by an unbiased Gaussian,

$$P_{noise}(\mu|\theta) = \sum_{\nu} e^{-\frac{(\mu-\nu)^2}{2\sigma^2}} P_{id}(\mu|\theta).$$

The Fisher information in the presence of noise is thus given by

$$F_{noise}(\theta) = \sum_{\mu} \frac{1}{P_{noise}(\mu|\theta)} \left(\frac{dP_{noise}(\mu|\theta)}{d\theta} \right)^2 .$$

This method proved very successful in Ref. [KRI11], and we are now applying it to the case of ultra cold atoms in collaboration with UHEI.

Although detection schemes sensitive to the atom number difference in the two-mode have important advantages, they can be fully exploited in case a defined number of atoms can be feed at the input of the interferometer. In particular for Heisenberg-limited sensitivity a control in the initial atom number at the level of single atom would be required, which is a challenging task. Therefore we decided initially to work on the implementation of detection techniques that aim at counting the atoms in the two modes independently, like the other partners are currently doing. In particular, we are currently setting up the apparatus to detect the fluorescence light emitted by the atoms loaded in deep optical lattices, one atom per site to prevent light assisted collisions.

References

[KRI11] R. Krischek, C. Schwemmer, W. Wieczorek, H. Weinfurter, P. Hyllus, L. Pezzé and A. Smerzi, Phys. Rev.Lett. **107**, 080504 (2011).