Q 2: Precision measurements and metrology I

Time: Monday 11:00–12:30 Location: F 128

Group Report Q 2.1 Mon 11:00 F 128

Quantum Metrology and Tomography with Bose–Einstein Condensates — •Roman Schmied, Caspar Ockeloen, Max Riedel, and Philipp Treutlein — Departement Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Schweiz

We present our recent results on the creation, manipulation, use, and analysis of entangled states of Bose–Einstein condensates of about 1000 Rubidium-87 atoms.

We have used a Bose–Einstein condensate as an interferometric scanning probe to map out a microwave field near a chip surface with a few micrometers resolution [1]. Using entanglement between the atoms we overcome the standard quantum limit of interferometry by 4 dB and maintain enhanced performance for interrogation times up to 20 ms. This demonstrates the usefulness of quantum metrology with entangled states when the particle number is limited due to the small probe size, and extends high-precision atomic magnetometry to the micrometer scale and microwave frequencies.

To analyze the many-body states of our Bose–Einstein condensates we extend our previously published quantum-state tomography [2] by enforcing that tomographically reconstructed many-body density matrices are positive semi-definite. We use this method to extract quantitative data such as the Fisher information.

[1] C.F. Ockeloen *et al.*, *submitted.*
[2] R. Schmied and P. Treutlein, New J. Phys. **13**, 065019 (2011).

Q 2.2 Mon 11:30 F 128

Noisy metrology beyond the standard quantum limit — •Rafael Chaves[1,2], Jonatan Bohr Brask[2], Marcin Markiewicz[3], Janek Kołodyński[4], and Antonio Acin[2,5] — [1]Institute for Physics, University of Freiburg, Germany — [2]ICFO-Institut de Ciències Fotòniques, Castelldefels (Barcelona), Spain — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, Poland — [4]Faculty of Physics, University of Warsaw, Poland — [5]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Parameter estimation is of fundamental importance in areas from atomic spectroscopy to gravitational wave-detection. Entangled probes provide a significant precision gain over classical strategies in the absence of noise. However, recent results seem to indicate that any small amount of realistic noise restricts the advantage of quantum strategies to an improvement by at most a multiplicative constant. We identify a relevant scenario in which one can overcome this restriction and attain super-classical precision scaling even in the presence of uncorrelated noise. We show that the quantum improvement can be significantly enlarged when the noise is concentrated along some spatial direction, while the Hamiltonian governing the evolution which depends on the parameter to be estimated can be engineered to point along a different direction. In particular, in the case of perpendicular orientation, we find a maximal asymptotic precision scaling of $1/N^{5/6}$, where N is the number of probe particles, and identify a state which achieves this.

Q 2.3 Mon 11:45 F 128

Accuracy Limits on the Estimation of the Magnetic Field Gradient — •Iagoba Apellaniz and Philipp Hyllus — University of the Basque Country, P. O. Box 644, E-48080 Bilbao, Spain.

Entanglement between particles is a useful resource for quantum information processing tasks as well as for quantum metrology. For instance, it allows us to have a metrological accuracy higher than the shot-noise limit. The accuracy in the estimation of the phase shift θ in a Mach-Zehnder Interferometer can be improved by a factor of $\sqrt{N}$ with respect to the shot-noise limit, $\Delta\theta \sim 1/\sqrt{N}$, where N is the number of particles on the system which are analyzed to estimate θ.

The usefulness of a multi-particle system for measuring the magnetic field gradient is investigated in Ref. [1]. They consider a multi-particle singlet state for this purpose and incorporate the information about the particle positions in the Hamiltonian.

In our presentation, we use a general Hamiltonian for this class of systems, and the information about the position of the particles involved is encoded in the state, not the Hamiltonian.

We investigate bounds on the sensitivity of measuring the magnetic field gradient, b_1, with a one dimensional N-particle system. We use the so-called Cramér-Rao bound and the Quantum Fisher Information (QFI) in order to get the bounds for the shot-noise limit and the Heisenberg limit.

[1] I. Urizar-Lanz, P. Hyllus, I. Egusquiza, M.W. Mitchell, G. Tóth, *Macroscopic singlet states for gradient magnetometry*, arxiv:1203.3797.

Q 2.4 Mon 12:00 F 128

Application of multipartite quantum states for gradient magnetometry — •Iñigo Urizar-Lanz[1], Philipp Hyllus[1], Iñigo Egusquiza[1], Morgan Mitchell[2], and Geza Toth[1,3,4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Institute of Photonic Sciences, ICFO, Mediterranean Technology Park, Barcelona, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary

Singlet states are states with vanishing angular momentum. We investigate the possibilities of these states for measuring the gradient of a magnetic field. This kind of magnetometry is invariant under a homogeneous magnetic field. We calculate the precision of the measurement for this type of states, as well as for other states that are not invariant under homogeneous fields. We also consider the case of spins larger than 1/2 and the effect of noise.

Q 2.5 Mon 12:15 F 128

Enhancement of a single electron spin based magnetometer by utilizing a small nuclear spin quantum register — •Sebastian Zaiser[1], Philipp Neumann[1], Gerald Waldherr[1], Fedor Jelezko[2], and Jörg Wrachtrup[2] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Institut für Quantenoptik, Universität Ulm

The negatively charged nitrogen-vacancy (NV) center in diamond and its associated nuclear spins form a versatile small quantum register. Apart from its potential applications in quantum information processing the susceptibility of its quantum coherence to external stimuli like magnetic and electric fields render the NV center a tiny quantum sensor. Its high spatial confinement allows to build very small sensing devices which lead to a sample-probe distance of only a few nanometers potentially enabling the detection of single electron or even nuclear spins.

Here we show how a small quantum register of proximal nuclear spins around the NV center can be used to drastically increase the performance of the NV electron spin as a magnetic field sensor.