Quantum state steering by real-time adaptive measurements on a single nuclear spin

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Abstract: We present our most recent results on partial measurements of a nuclear spin in which the inevitable measurement back-action is controllably reduced. The post-selected measurement results can give rise to weak values. By using a real-time adaptive scheme the quantum state can be tuned using only measurements.

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1. Main Text

1.1. Weak Measurements

Quantum measurements form a topic of great interest to both the theoretical and experimental quantum physics community. From a fundamental point of view there are still unsolved questions regarding the apparent collapse of the wavefunction. At the same time quantum measurements play an essential role in quantum information schemes such as teleportation and quantum error correction. The ability to perform a quantum measurement in a highly controlled experimental environment is essential to our understanding and for developing new techniques.

However, it is challenging to measure a quantum state while maintaining its quantum coherence since a quantum state is easily perturbed by experimental errors (measurement crosstalk) and by the inevitable measurement induced back action. By applying variable strength measurements, the kick-back from this partial measurement can be reduced at the cost of loss of information. These so-called weak measurements [1] are shown to behave counter intuitively upon post selection. The measurement outcomes produce weak values that could never be obtained with fully projective measurements. Furthermore they can be used in continuous feedback schemes to preserve a quantum state [2]. Here we will present our latest results on implementing weak measurements in the Nitrogen-Vacency center in diamond.

1.2. NV-center

The NV-center, consisting of a substitutional nitrogen atom and an adjacent vacancy in the diamond lattice, has recently emerged as an excellent test bed for quantum information protocols. The NV's electronic spin can be initialized, manipulated and read out in a single shot. This high-fidelity control recently enabled the remote entanglement of two electronic spins in two diamonds separated by a distance of three meters [3].

The Nitrogen atom also carries a nuclear spin, making the NV-center an intrinsic two-qubit system. Using the electron spin as a probe, this nuclear spin can also be initialized and readout optically and be entangled with another nuclear spin in the environment in a measurement-based entanglement protocol [4]. The same techniques allowed the implementation of the quantum three-box problem using fully projective measurements [5].

1.3. Partial measurements of the nuclear spin

We will present our latest results on implementing tunable-strength measurements by first partially entangling the nuclear spin with the electronic spin and then performing a protective readout of the electron spin. Varying the time in a ramsey-fringe-type experiment, in which the two spins interact via the hyperfine interaction, controls the amount of entanglement. This allows for a precise tuning of the measurement strength. With this tool at hand, properties of quantum measurements such as weak values or the gradual collapse of the wave function can be observed.

1.4. Real-time steering by measurement

Partial measurements are important for continuous quantum feedback, since they allow to obtain information about a system without completely destroying it. In a typical control scheme a classical control pulse is applied to the system, based on the results of repeated partial measurements. It was recently proposed that one could also use the backaction of a partial measurement itself as the control [6]. We show our most recent results on the implementation of such a ”control-free control” feedback scheme, where the strength of a partial measurement is adjusted according to the result of the previous measurement.

References

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