Device-Independent Certification of a 398 m Link for Future Quantum Networks

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Abstract

We report the first device-independent certification of entanglement distribution over a macroscopic distance. Our setup consists of two single Rubidium atoms in traps separated by 398 m and connected with a 700 m fiber link. This quantum link is suitable for integration in a quantum network enabling a guarantee for security which is independent of the actual implementation.

Certification of complex devices is an important requirement for their application, especially in security-related scenarios. One of the strongest ways to test components is the so-called "device-independent" one, where no knowledge about or trust in their internal workings is required. Self-testing is a method for device-independent certification of entanglement using the result of a Bell test. Here we present the successful distribution of entanglement over 398 meters confirmed by the device-independent certification of the Bell state fidelity. For this we extended the self-testing formalism, accounting for the finite statistics and small imperfections of the employed random number generators to give reliable confidence intervals for the average state fidelity [1].

The key ingredients of our experiment are heralded entanglement of single trapped ^{87}Rb atoms distributed over a distance of 398 m. To achieve this two remote atoms are independently optically excited to emit a photon each, whose polarization is entangled with the respective atomic spin states. The photons are sent to a station where a Bell state measurement is implemented with a fiber beamsplitter followed by a polarizing beamsplitter at each output port and four single photon detectors. The detection of two-photon coincidences swaps the entanglement to the atoms and heralds its creation. The heralding signal triggers a highly reliable and fast atomic state readout based on state selective ionization and subsequent detection of ionization fragments. This setup enabled us to violate Bell's inequality while closing the major experimental loopholes [2], which also guarantees all requirements for device-independent certification [1] without auxiliary assumptions. The employed method for entangling remote quantum memories forms a basic building block of future quantum networks.

In contrast to the Bell experiment [2] we now employ a pre-selection on the heralding events based on an ab-inito model of the entanglement creation. This allows to optimize the experimental process for a higher state fidelity at the cost of event rate. We report a device-independent state fidelity of $F \geq 55.54\%$ with a confidence level of 99% for the Ψ^- Bell state. The demonstrated result is the first device-independent certification of entanglement distribution. As it is based on a loophole-free Bell test, the certification does not rely on any assumption about the Hilbert space dimension or on how the preparation or measurement devices work. This proves that our link guarantees security that is independent of the details of the actual implementation.

[1] J.-D. Bancal, K. Redeker, P. Sekatski, W. Rosenfeld, N. Sangouard, *Device-independent certification of an elementary quantum network link*, arXiv:1812.09117 (2018).

[2] W. Rosenfeld, D. Burchardt, R. Garthoff, K. Redeker, N. Ortegel, M. Rau, H. Weinfurter, *Event-Ready Bell Test Using Entangled Atoms Simultaneously Closing Detection and Locality Loopholes*, Phys. Rev. Lett. **119**, 010402 (2017).