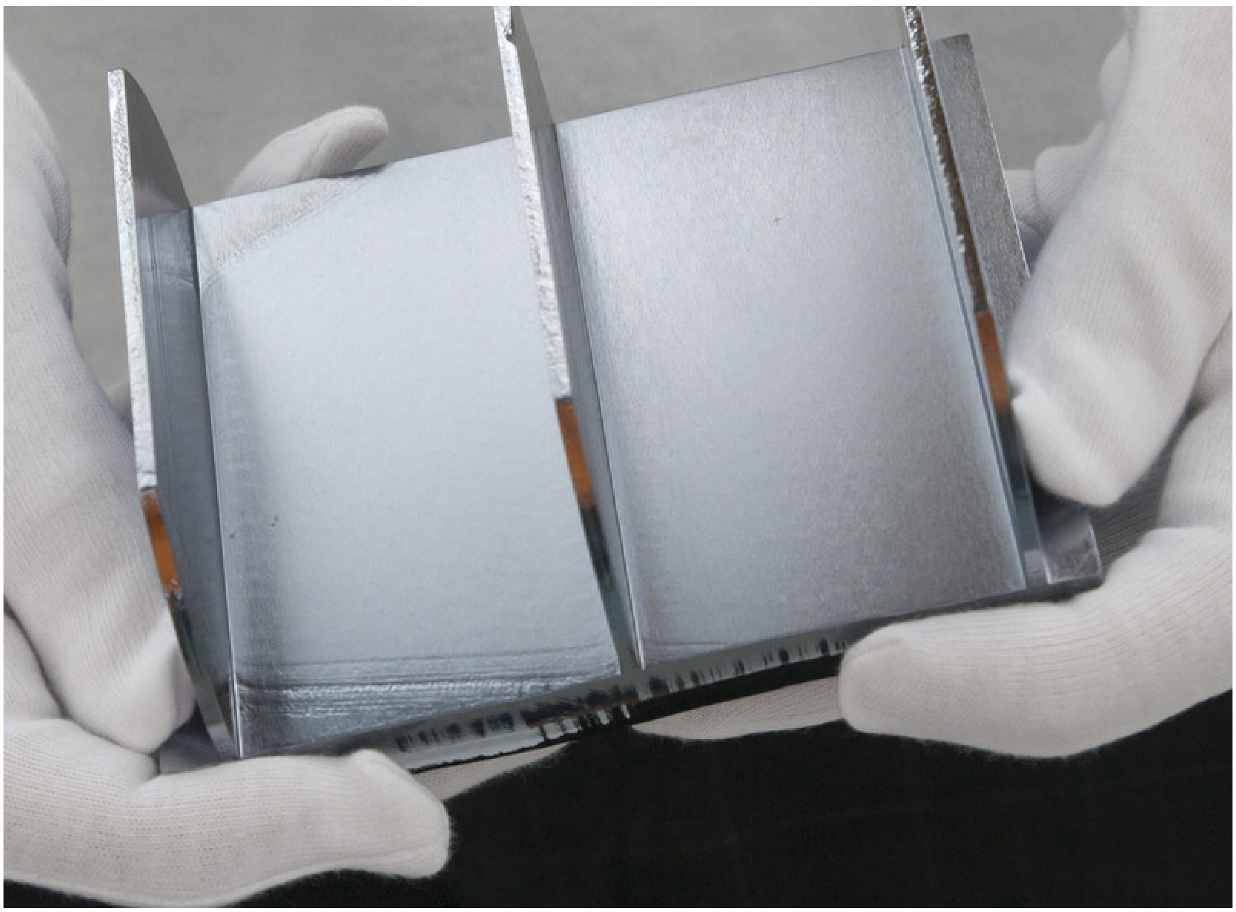
New method allows for quick, precise measurement of quantum states

January 12 2017



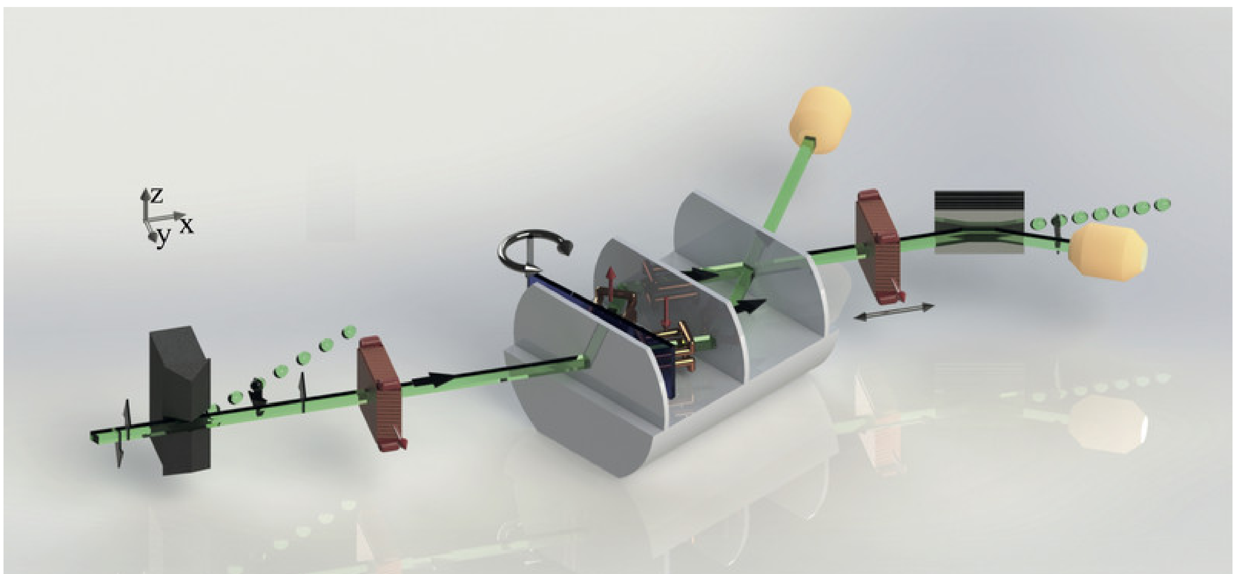
Triple Laue (LLL) neutron interferometer. Credit: Vienna University of Technology

Nuclear spin tomography is an application in medicine. The patient absorbs and re-emits electromagnetic radiation in all directions, which is detected and reconstructed as 3-D images or 2-D slice images. In a fundamental science laboratory, quantum state tomography is the process of completely characterizing the quantum state of an object as it is emitted by its source, before a possible measurement or interaction with the environment takes place.

This technique has become an essential tool in the emerging field of quantum technologies. The theoretical framework of quantum state tomography dates back to the 1970s. Its experimental implementations are nowadays routinely carried out in a wide variety of quantum systems. The basic principle of quantum state tomography is to repeatedly perform measurements from different spatial directions on quantum systems in order to uniquely identify the system's quantum state. This requires a lot of computational post-processing of the measured data to deduce the initial quantum state from the observed measurement results.

Consequently, in 2011, a novel, more direct tomographical method was established to determine the quantum state without the need for post-processing. However, that novel method had a major drawback: It uses minimally disturbing measurements, so-called weak measurements, to determine the system's quantum state. The basic idea behind weak measurements is to gain very little information about the observed system by keeping the disturbance of the measurement process negligible. Usually, making a measurement has a huge impact on a quantum system, causing quantum phenomena like entanglement or interference to vanish irretrievably.

Since the amount of information gained via this procedure is very small, the measurements have to be repeated multiple times—a huge disadvantage of this measurement procedure in practical applications. A research team at the Institute of Atomic and Subatomic Physics of TU Wien headed by Stephan Sponar has managed to combine these two methods. "We were able to further develop the established method so that the need of weak measurements becomes obsolete. Thus, we were able to integrate usual, so-called strong measurements, in the direct measurement procedure of the quantum state. Consequently, it is possible to determine the quantum state with higher precision and accuracy in a much shorter time compared to the approach with weak measurements—a tremendous advance,", explains Tobias Denkmayr the first author of the paper. These results have now been published in the journal *Physical Review Letters*.



Schematic illustration of the interferometric setup. Credit: Vienna University of Technology

Neutron interferometry—the new method of choice

An experimental test of the new scheme in a neutron interferometric experiment was carried out by Sponar and his team. It is based on the wave nature of neutrons, which are massive nuclear constituents forming almost two-thirds of the universe. Nevertheless, if they are isolated from the atomic nucleus—for example, in the fission process of a research reactor—they behave like waves. This phenomenon is usually referred to as wave-particle duality, which is explained in the framework of quantum mechanics. Inside the interferometer, an incident beam is split into two separate beams by a thin, perfect silicon crystal plate. The beams travel along different paths in space, and at some point are recombined and allowed to interfere. The experiment was done at the neutron source at the Institut Laue-Langevin (ILL) in Grenoble, where the group of the Institute of Atomic and Subatomic Physics is in charge of a permanent beam port.

It is important to note that the results are not limited to the quantum system formed by single neutrons, but are, in fact, completely general. Therefore, they can be applied to many other quantum systems such as photons, trapped ions or superconducting qubits. The results may have a big impact on how quantum state estimation is performed in the future and could be exploited in the rapidly evolving technologies applied in quantum information science.

More information: Tobias Denkmayr et al, Experimental Demonstration of Direct Path State Characterization by Strongly Measuring Weak Values in a Matter-Wave Interferometer, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.118.010402

Provided by Vienna University of Technology