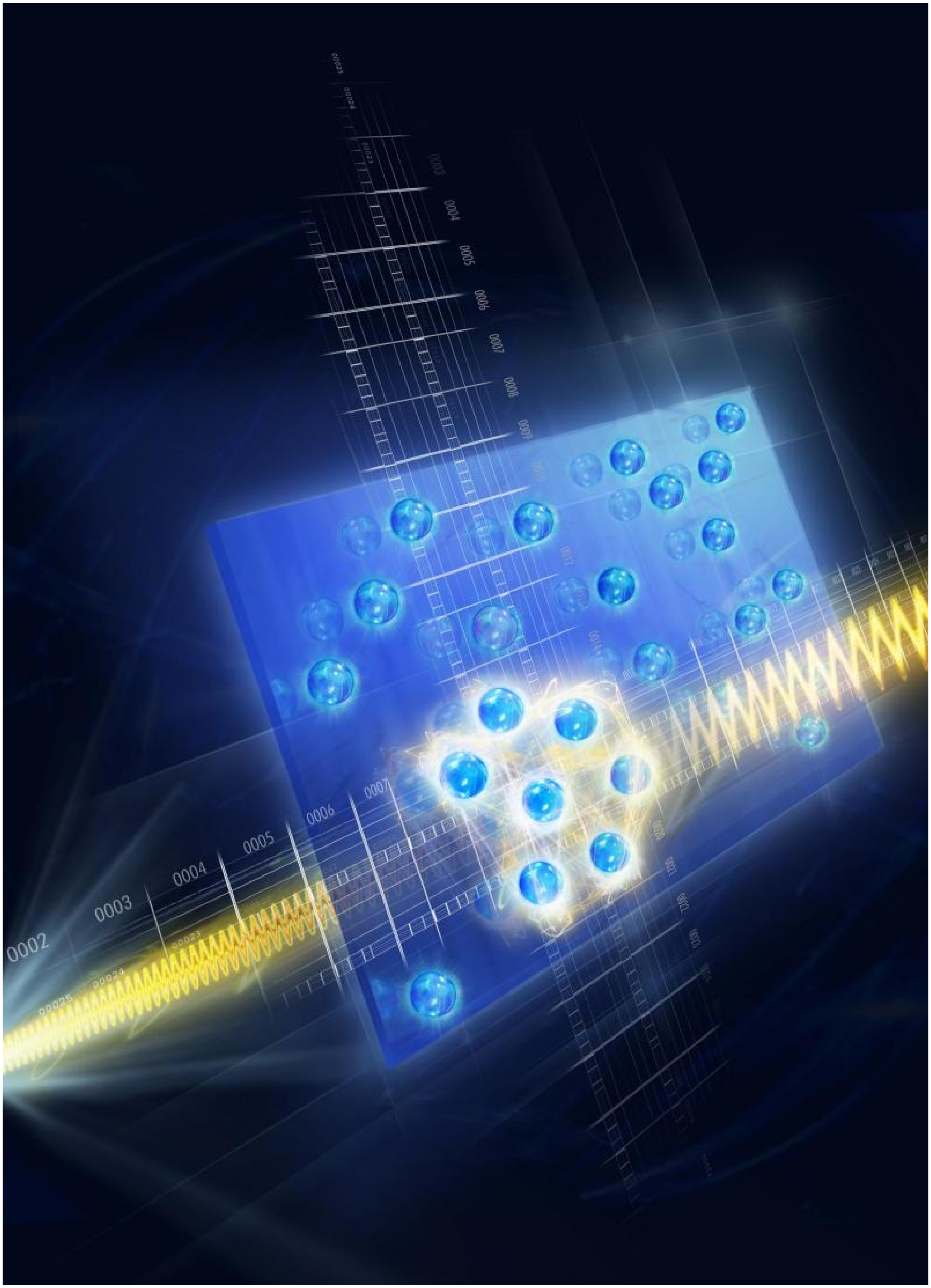
New protocol to detect entanglement of many-particle quantum states

March 21 2016


0002
0003
0004
0005
0006
0007

Quantum systems consisting of many particles can enter highly intricate states with strong so-called multiparticle entanglement. A new-found theoretical relation now allows extracting it with standard tools available in scattering experiments. Credit: IQOQI/Ritsch

Physicists have developed a new protocol to detect entanglement of many-particle quantum states using a much easier approach. The new protocol, now published in *Nature Physics*, is particularly interesting for characterizing entanglement in systems involving many particles. These systems could help us not only to improve our understanding of matter but to develop measurement techniques beyond current existing technologies.

In quantum theory, interactions among particles create fascinating correlations known as entanglement that cannot be explained by any means known to the classical world. Entanglement is a consequence of the probabilistic rules of quantum mechanics and seems to permit a peculiar instantaneous connection between particles over long distances that defies the laws of our macroscopic world - a phenomenon that Einstein referred to as "spooky action at a distance."

Developing protocols to detect and quantify entanglement of many-particle quantum states is a key challenge for current experiments because entanglement becomes very difficult to study when many particles are involved. "We are able to control smaller particle ensembles well, where we can measure entanglement in a relatively straight forward way," says quantum physicist Philipp Hauke. However, "when we are dealing with a large system of entangled particles, this measurement is extremely complex or rather impossible because the resources required scale exponentially with the system size."

Philipp Hauke and Peter Zoller from the Department of Theoretical Physics at the University of Innsbruck and the Institute for Quantum Optics and Quantum Information (IQOQI) at the Austrian Academy of Sciences in collaboration with Markus Heyl from the Technical University of Munich, and Luca Tagliacozzo from ICFO - The Institute of Photonic Sciences have found a new way to detect certain properties of many-particle entanglement independent of the size of the system and by using standard measurement tools.

Entanglement measurable via susceptibility

"When dealing with more complex systems, scientists had to carry out a large number of measurements to detect and quantify entanglement between many particles," says Philipp Hauke. "Our protocol avoids this problem and can also be used for determining entanglement in macroscopic objects, which was nearly impossible until now."

With this new method theoretical physicists are able to use tools already well established experimentally. In their study, published in *Nature Physics*, the team of researchers give explicit examples to demonstrate their framework: The entanglement of many-particle systems trapped in optical lattices can be determined by laser spectroscopy, and the well-established technique of neutron scattering may be used for measuring it in solid-state systems. As the physicists have been able to show, the quantum Fisher information, which represents a reliable witness for genuinely multipartite entanglement, is in fact measurable. The researchers have highlighted that entanglement can be detected by measuring the dynamic response of a system caused by a perturbation, which can be determined by comparing individual measurements. "For example, when we move a sample through a time-dependent magnetic field, we can determine the system's susceptibility towards the magnetic field through the measurement data and thereby detect and quantify internal entanglement," explains Hauke.

Manifold applications

Quantum metrology, i.e. measurement techniques with increased precision exploiting quantum mechanics, is not the only important field of application of this protocol. It will also provide new perspectives for quantum simulations, where quantum entanglement is used as a resource for studying properties of quantum systems. In solid-state physics, the protocol may be used to investigate the role of entanglement in many-body systems, thereby providing a deeper understanding of quantum matter.

More information: Measuring multipartite entanglement through dynamic susceptibilities, *Nature Physics*, DOI: 10.1038/nphys3700

Provided by University of Innsbruck