Experimentally testing nonlocality in many-body systems

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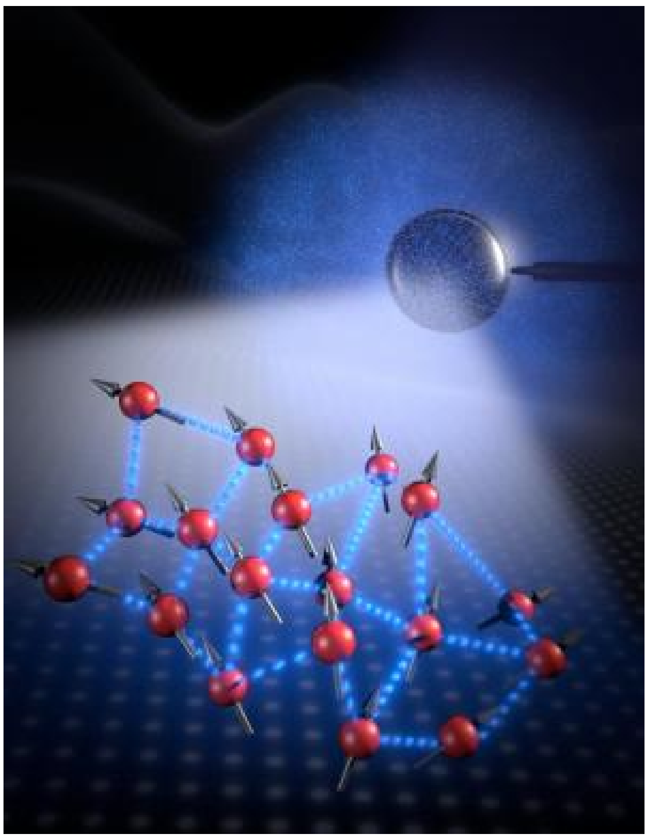

This image depicts an artistic impression of the experiment. Credit: ICFO

In a recent study published in Science, researchers at ICFO construct multipartite Bell inequalities built from the easiest-to-measure quantities, the two-body correlators, which are capable of revealing nonlocality in many-body systems. As these are considered a fundamental resource for quantum information theory, this study will pave a new path towards experimental detection of nonlocality in large composite quantum systems.

Science has recently published a study carried out by researchers at ICFO in collaboration with the Institute for Nuclear Research, Hungarian Academy of Sciences, which demonstrates the capability of detecting non-locality in many-body quantum systems by constructing multipartite Bell inequalities involving only two-body correlations.

In Quantum Theory, interactions among particles create fascinating correlations that cannot be explained by any means known to the Classical World. These correlations, usually known to be nonlocal, prove that the Quantum and Classical Worlds differ at the level of elementary particles. They have also become a powerful resource over the years for such real-world applications as the generation of cryptographic keys, which are perfectly secure against any malicious adversary, or perfect random number generators, which are crucial for cryptography, the numerical simulations of complex systems or fair gambling. Last but not least, these nonlocal correlations, aside from entanglement, are expected to shed a completely new light on our understanding of the physics of many-body quantum states.

An important goal for researchers in this field has been to confirm that such nonlocal correlations really exist in Nature. To date, experiments have focussed on the observation of nonlocality in only small quantum systems consisting of few particles, leaving more complex quantum systems completely unstudied. This is simply because the known tools that may reveal nonlocality, the so-called Bell inequalities, involve correlations among many parties that are still out of reach of the current experimental technology dealing with many-body quantum systems.

In this study, the research team at ICFO, comprised by Jordi Tura, Remigiusz Augusiak, Belen Sainz and ICREA Professors at ICFO Antonio Acín and Maciej Lewenstein, in collaboration with T. Vértesi from Hungary, designed classes of multipartite Bell inequalities constructed from the easiest-to-measure quantities, the two-body correlators. They showed that these inequalities are capable of revealing the nonlocality properties of several interesting many-body quantum states, in particular those relevant for nuclear and atomic physics.

They were even able to show that the inequalities proposed by this study could be verified experimentally by measuring the total spin components of the particles, thus opening a wide range of new possibilities for experimental detection of many-body nonlocality in physical systems in which individual particles cannot be addressed. Possible experimental setups in which these inequalities can be studied include cold atomic clouds and the so-called atomic ensembles, ultracold atoms (Bose condensates or spinor Bose condensates) as well as systems of atoms trapped in nanostructures, or systems of trapped ions.

In summary, the authors comment that "Our study has shown that the possibility of experimentally confirming the existence of nonlocal correlations in many-body quantum states is becoming accessible to physicists, something unimaginable before. At the fundamental level, any experiment regarding this matter would certainly provide a new proof that quantum theory correctly describes nature, even when considering complex many-body systems. In practice, a better characterization of these correlations in many-body quantum systems could not only help to create new understanding, it could lead to new applications, for instance in quantum metrology, and in particular in quantum magnetometry.

More information: "Detecting nonlocality in many-body quantum states", J. Tura, R. Augusiak, A. B. Sainz, T. Vértesi, M. Lewenstein, A. Acín, 2014, *Science*, DOI: 10.1126/science.1247715

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