Detecting the nonlocality of many-body quantum states

J. Tura[1], R. Augusiak[1], A. B. Sainz[1], T. Vértesi[2], M. Lewenstein[1, 3] and A. Acín[1, 3]

[1]ICFO-Institut de Ciències Fotòniques, 08860 Castelldefels (Barcelona), Spain
[2]Institute for Nuclear Research, Hungarian Academy of Sciences, H-4001 Debrecen, P.O. Box 51, Hungary
[3]ICREA-Institució Catalana de Recerca i Estudis avançats, Lluis Companys 23, 08010 Barcelona, Spain
E-mail: maciej.lewenstein@icfo.es

One of the most important steps in the understanding of quantum many-body systems is due to the intensive studies of their entanglement properties [1,2]. Much less, however, is known about the role of quantum nonlocality [2] in these systems. This is because standard many body observables involve correlations among few particles, while there is no multipartite Bell inequality for this scenario.

In the introduction I will discuss shortly the role of entanglement in many body systems, stressing the difference between the gapped and critical systems. I will then concentrate on the results of Refs. [4], where we provide the first examples of nonlocality detection in many-body systems using two-body correlations. To this aim, we construct families of multipartite Bell inequalities that involve only second order correlations of local observables. We then provide examples of systems, relevant for nuclear and atomic physics, whose ground states violate our Bell inequalities for any number of constituents. Finally, we identify inequalities that can be tested by measuring collective spin components, opening the way to the experimental detection of many-body nonlocality, for instance with atomic ensembles [5], systems of trapped ions [6], or atoms trapped close to nano-structured (tapered) fibers and photonic crystals [7].

References

[1] A. Osterloh *et al.*, Nature **416**, 608 (2002); T. J. Osborne *et al.*, Quantum Inf. Proc. **1**, 45 (2002); Phys. Rev. A **66**, 032110 (2002); G. Vidal *et al.*, Phys. Rev. Lett. **90** 227902 (2003).
[2] M. Lewenstein, A. Sanpera, and V. Ahufinger, *"Ultracold atoms in Optical Lattices: simulating quantum many body physics"*, Oxford University Press, Oxford, 2012, ISBN 978-0-19-957312-7.
[3] J. S. Bell, Physics **1**, 195-200 (1964).
[4] J. Tura *et al.*, arXiv:1306.6860 [quant-ph] (2013), *Detecting the non-locality of quantum many body states* Science **344**, 1256 (2014); J. Tura *et al.*, *Translationally invariant Bell inequalities with two-body correlators*, arXiv:1312.0265, J. Phys. A: Math. Theor. **47,** 424024 (2014), special issue of J. Phys. A on "50 years of Bell's Theorem".
[5] K. Hammerer *et al.*, Rev. Mod. Phys. **82**, 1041 (2010). K. Eckert *et al.*, Nature Phys. **4**, 50 (2008).
[6] T. Graß and M. Lewenstein, *Trapped-ion quantum simulation of tunable-range Heisenberg chains*, arXiv:1401.6414, EPJ Quantum Technology 2014, **1**:8, doi:10.1186/epjqt8.
[7] J. S. Douglas, H. Habibian, A. V. Gorshkov, H. J. Kimble, D. E. Chang, Atom induced cavities and tunable long-range interactions between atoms trapped near photonic crystals, arXiv:1312.2435.