Universität Basel

Research Project

Certifying the quantum nature of complex systems from Bell's theorem

Third-party funded project

Project title Certifying the quantum nature of complex systems from Bell's theorem
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In 1964, John Bell studied a simple game in which two black-boxes receive classical inputs and produce classical outputs only. He devised a test to certify that the correlations between the outputs cannot be explained by classical means from the sole knowledge of the input/output statistics. While this test – now known as a Bell test – is appealing to highlight limits of classical physics, it has been realized in 1992 that it can be used to certify that the state on which the black boxes operate is a well identified entangled state. As entanglement is at the core of secure communication, the Bell test is nowadays seen as a trustworthy technique to certify the security of communication tools, independently of the details and imperfections of the actual implementations.

Although the Bell test occupies a privileged position in physics at the interface between funda- mental and applied physics, it has been implemented in small systems only, involving at most 14 particles. We took the next step during my SNSF professorship by showing how it can be applied to large systems. In collaboration with the Treutlein group in Basel, we succeeded in witnessing Bell-correlations between hundreds of spins, that is, we have shown that the correlations between hundreds of atoms in a Bose-Einstein condensate can be strong enough to violate a Bell inequality. The first aim of the extension of my professorship is to build upon these initial results and create a complete mathematical framework for the characterization of quantum multi-partite and many-body systems from Bell tests. We will clarify the relation between key forms of quantum correlations like entanglement and Bell correlations. We will develop practical tools to quantify these quantum correlations in multi-partite systems. We will also work on statistical issues to understand how quantum many-body systems compare with their classical counterparts when working with finite statistics. Upon success, we will lay the theoretical groundwork that is needed to report on the first Bell test with a many-body system, hence demonstrating its quantum nature in a fully black-box scenario.

The second objective of my project is to highlight the potential of Bell tests to certify the proper functioning of complex quantum technologies that are not necessarily trusted and are anyway too complicated to be modelled accurately. In particular, we will lay the basis for a completely new class of certification methods for arbitrary channels. We will show how they can be used to certify quantum memories and following a recent proposal that has been granted by the SNSF in September 2017, we will also apply them to quantum computing. We will work in close collaboration with leading experimental groups and upon success, we will participate to the first-proof-of-principle experiments certifying complex quantum technologies by demonstrating that they behave as instructed even when using imperfectly described systems. The one billion euro flagship initiative for quantum technologies that will be launch in 2018 makes this research line very timely.

In summary, I propose to work on basic theoretical questions, while maintaining close connections with cutting edge experiments. This connection with experiments is the great strength of my project, and my collaborations with experimental groups at Basel and beyond, provide the perfect atmosphere for innovative findings in diverse areas of fundamental and applied physics.

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