Theoretical Quantum Physics

Group Seminar

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Online (Zoom)

Spatial Indistinguishability as a Directly Controllable Quantum Resource

Rosario Lo Franco

University of Palermo

Abstract

Quantum information and computation processing requires the control of suitable resources by feasible operations and measurements on the composite quantum system. The building blocks (particles) of quantum networks are usually identical subsystems (e.g., physical qubits, two-level atoms, photons, electrons, quasiparticles), which can be bosons or fermions [1–3]. When the composite system is made of non-identical (or distinguishable) particles, the well-established operational framework employed to exploit their quantum resources, such as entanglement or coherence, is based on local operations and classical communication (LOCC) [4]. Local operations within the LOCC framework are meant as applied to each individual particle (particle-locality). Of course, this is not possible for quantum networks made of spatially overlapping identical particles which are indistinguishable and individually unaddressable. The direct identification and utilization of quantum resources in systems of identical particles has therefore remained elusive and challenging. This issue has been hindering the desired development of quantum-enhanced technology based on identical particles.

Christian Schilling
c.schilling@physik.uni-muenchen,de
Theresienstr. 37

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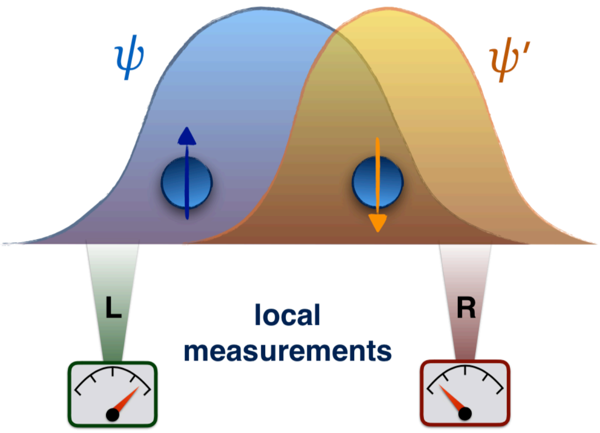

FIG. 1. Sketch of the sLOCC operational framework.

The fundamental question whether spatial indistinguishability by itself can be an exploitable resource for quantum information processing arises in this context. The problem assumes interest when the spatial wave functions of the identical particles overlap, so that the particles share common regions of space where they can stay and be detected. A natural solution to the problem would be supplied by an approach suitably introduced to harness identical particles under general conditions. In this talk, we discuss at an introductory level our most recent results about this purpose and its related practical consequences.

In particular, we first explain the original particle-based approach to deal with states of identical particles without resorting to fictitious labels [5–7]. Then, we describe the operational framework based on spatially localized operations and classical communication (sLOCC), where the term "local" is now meant likewise in quantum field theory, that is as a localized region of space [8]. The sLOCC framework (see Fig. 1) allows one to address the internal degrees of freedom of the particles and quantify quantum traits, like entanglement, due to a given degree of spatial indistinguishability under generic spatial overlap configurations [8, 9]. We highlight that this operational entanglement crucially depends on both relative spatial overlap between particle wave functions and measurement regions. This spatial indistinguishability can be tuned, enabling any quantum information task between separated nodes (e.g., teleportation), as also reported experimentally [10], and protecting quantumness against detrimental local noises.

Christian Schilling
c.schilling@physik.uni-muenchen,de
Theresienstr. 37
Emmy
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These results make it clearly emerge that spatial indistinguishability, stemming from the spatial overlap of identical particles, constitutes a directly controllable operational resource. They open the way to further quantum-enhanced applications in experimental contexts where identical subsystems are the constituents of quantum networks, from all-optical setups [10–13] to quantum atomic circuits [14].

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Christian Schilling
c.schilling@physik.uni-muenchen,de
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