INTERNSHIP PROPOSAL

(One page maximum)

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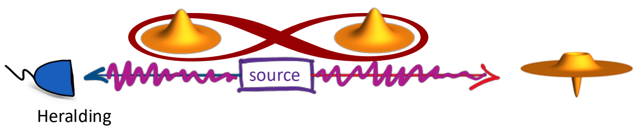
Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: PEPR

Bell nonlocality as a resource for quantum technologies

Quantum correlations have sparked the interest of both experimental and theoretical quantum researchers. Not only do they teach us something about the surprising properties of nature, but they also pave the road towards technological applications. The most notorious types of quantum correlations are those that are manifestly nonlocal and allow us to violate Bell inequalities [1]. While these exotic correlations are notoriously difficult to achieve and protect, they are a core resource for device-independent quantum communication protocols. Yet, beyond the realm of quantum communication, Bell nonlocality has not often been explored as a key technological resource. In this project, we aim to change that.

In absence of nonlocal quantum correlations, Bell's local hidden-variable model puts constraints on the measurement statistics. These constraints are at the root of Bell inequalities, but, in principle, they also put limitations on the use of our quantum states. In this project, we will focus on continuous-variable systems, which means that we deal with a bosonic system (e.g. light) upon which we perform homodyne measurements. Within the context of such systems, the student will have the choice to explore one of the following applications: quantum state engineering or quantum metrology.



In the context of *quantum state engineering*, we will consider heralding schemes. In such a setup, we consider a bipartite quantum state in which on part of the system is measured to project the other part of the system into a desired, often more exotic, quantum state. It was already shown that, in the heralding scenario, certain types of quantum correlations are necessary or sufficient to produce quantum properties such as negativity of the Wigner function [2,3]. However, it is not clear whether there are properties that can only be generated through nonlocality. The student will try to answer this question by classifying the types of states that can be generated under the assumption that the initial bipartite state can be described by a local hidden-variable model.

Alternative, the student might also choose to explore the context of *quantum metrology*, and more specifically multiparameter estimation. Here, we assume that a multipartite quantum system has several unknown parameters. The precision with which local parameters can be jointly estimate can be enhanced by quantum correlations. This idea was used in the past to derive witnesses for entanglement [4] and quantum steering [5]. However, this approach has never been extended to nonlocality. Yet, we know that local hidden-variable models constrain the measurement statistics, and thus also its capabilities to estimate parameters. By characterising these constraints, we ultimately seek to identify a metrological Bell inequality.

References

[1] N. Brunner, D. Cavalcanti, S. Pironio, V. Scarani, and S. Wehner, Rev. Mod. Phys. 86, 419 (2014).
[2] M. Walschaers PRX Quantum 2, 030204 (2021)
[3] M. Walschaers Quantum 7, 1038 (2023).
[4] C. E. Lopetegui, M. Isoard, N. Treps, and M. Walschaers, Optica Quantum 3, 312-328 (2025)
[5] C. E. Lopetegui, M. Gessner, M. Fadel, N. Treps, and M. Walschaers, PRX Quantum 3, 030347 (2022).

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: NO Soft Matter and Biological Physics:NO
Quantum Physics: YES Theoretical Physics: YES