INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire Matériaux et Phénomènes Quantique
CNRS identification code: UMR 7162
Internship director'surname: Pérola Millman & Arne Keller
e-mail: perola.milman@u-paris.fr Phone number:
Web page:
Internship location: 10, rue Alice Domon et Léonie Duquet 75013 Paris

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

Quantum information in quantum optics and superselection rules

Quantum information protocols are rigorously defined within a mathematical framework, and several benchmarks exist for identifying the resources required to achieve potential quantum advantage—for instance, negativities of the discrete Wigner function or so-called "magic." At the same time, physical systems, in particular bosonic systems such as the quantum electromagnetic field, can be used to encode quantum information or, equivalently, to simulate quantum information protocols. However, in such systems the "magical" resources that enable quantum advantage over classical simulations are subject to physical constraints, including symmetries and conservation laws. While abstract qubits carry no intrinsic symmetry, photons are bosons—symmetric, identical particles, and this has consequences on the authorized manipulations of quantum states.

During this internship, we will study the interplay between physical and informational resources, with a focus on how detection itself may be regarded as a non-classical resource in quantum-optics-based quantum information protocols. One important aspect of detection is that it is directly related to the choice of computational basis, in some protocols, and can be used to implement quantum gates, or transform the quantum states in measurement based schemes. Our approach will involve developing an original framework in which the phase reference of quantum optical states is explicitly treated as a resource. This is known as the superselection role compliant framework, that has been proven to be a valuable tool to assess the quantum informational content of bosonic states [1] and provide an unifying framework of the resources which are necessary for quantum advantage in quantum metrology [2] and in quantum information [3]. Typically, the phase reference is implicit and overlooked, which obscures the evaluation of resource trade-offs in bosonic quantum information protocols. By explicitly incorporating it to describe the detection of photons in different regimes, we will analyze, in particular, how detection contributes to the quantum advantage observed in BosonSampling protocols and what are the true resources of the homodyne detection, a detection technique that is often regarded as resource-free.

Ideally, we would like to connect our results and investigations with the twin-photon platform developed by Sara Ducci's group, in our team (see, for instance [4]).

[1] E. Descamps et al., Phys. Rev. Lett. 133, 160605 (2024).
[2] A. Saharyan et al. arXiv: 2507.13245 (2025).
[3] E. Descamps et al. arXiv: 2501.03943 (2025).
[4] O. Meskine et al. Phys. Rev. Lett. 132, 193603 (2024).

Theoretical internship requiring a background in quantum mechanics and a keen interest in quantum information and quantum optics. Possible (and encouraged) collaboration with experimentalists (Sara Ducci's team, MPQ).

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

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