Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: Paris Institute of Nanosciences (INSP) and Laboratorie Kastler Brossel (LKB)
CNRS identification code: UMR 7588 (INSP) et UMR8552 (LKB)
Internship director'surname: Hugo Defienne and Sylvain Gigan (co-supervisor)
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Web page: www.quantumimagingparis.fr
Internship location (main): Sorbonne Université, campus Jussieu. 4 place Jussieu 75005 Paris
Thesis possibility after internship: YES Funding: NO

Title: Manipulating entangled photons through complex media

Topics: Experimental quantum optics, quantum imaging, optics in complex media.

Summary: Quantum entanglement lies at the heart of many quantum optical technologies, including quantum communications, computing, and imaging. However, when photons propagate through "disordered" optical environments - such as atmospheric turbulence in free-space communication or scattering tissue in imaging - their properties are disrupted, often significantly reducing the performance of quantum protocols. Understanding, controlling, or compensating for such optical disorder and its effects on entangled states is therefore a fundamental challenge for next-generation quantum technologies.

In collaboration with Prof. Gigan's group at LKB, we explore the propagation of two-photon entangled states through disordered media, developing techniques to manipulate and preserve their quantum properties. For instance, we recently demonstrated that wavefront shaping methods, initially developed for structuring classical light, can be adapted to compensate for scattering and transmit quantum entanglement through diffusive layers [1,2]. Interestingly, in some cases, we also showed that optical disorder can be exploited - rather than fought - to violate Bell inequalities through multimode fibers, enabling entanglement distribution across fiber networks [3]. This Master's internship - ideally leading to a PhD - builds directly on these results. Combining the expertise of Dr. Defienne's team in quantum imaging and Prof. Gigan's group in wavefront shaping, the project aims to transmit complex forms of entangled states (e.g. polarization and/or space) through even more complex media (e.g. multi-scattering layers such as paint). To this end, we aim to develop a new *multi-plane wavefront shaping approach*, which relies on multiple reflections on a spatial light modulator. This concept is inspired by recent advances on the so-called multi-plane light converter [4,5].

Candidate Profile: The ideal candidate should have strong experimental and theoretical skills in optics, quantum physics, quantum optics, and nonlinear optics. Prior experience in optics labs or experimental courses is highly desirable.

Research Environment: The student will join the Quantum Imaging Paris team, based at Sorbonne University's INSP. The internship will be co-supervised by Prof. Gigan at LKB. The student will primarily work on two experimental setups, located at INSP and LKB. The INSP team, led by Dr. Hugo Defienne, is very dynamic and consists of 4 international PhD students and 2 postdocs. We value a fun, fully open, and inclusive atmosphere!

References: [1] Courme et al. Non-classical optimization through complex media. arXiv:2503.24283 (2025); [2] Courme et al. Manipulation and certification of high-dimensional entanglement through a scattering medium. PRX Quantum, 4(1), 010308 (2023); [3] Courme et al. Harnessing disorder for Bell inequalities violation. In preparation (2025); [4] Lib et al. Processing Entangled Photons in High Dimensions with a Programmable Light Converter, PRL 18, 014063 (2022); [5] Kupianskyi et al, All-optically untangling light propagation through multimode fibers. Optica 11, 1, pp. 101-112 (2024).

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Starting dates: Internship: between Jan and May 2026 | Phd: Between Sept and Nov 2026

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