Laboratoire Matériaux et Phénomènes Quantiques

PhD proposal

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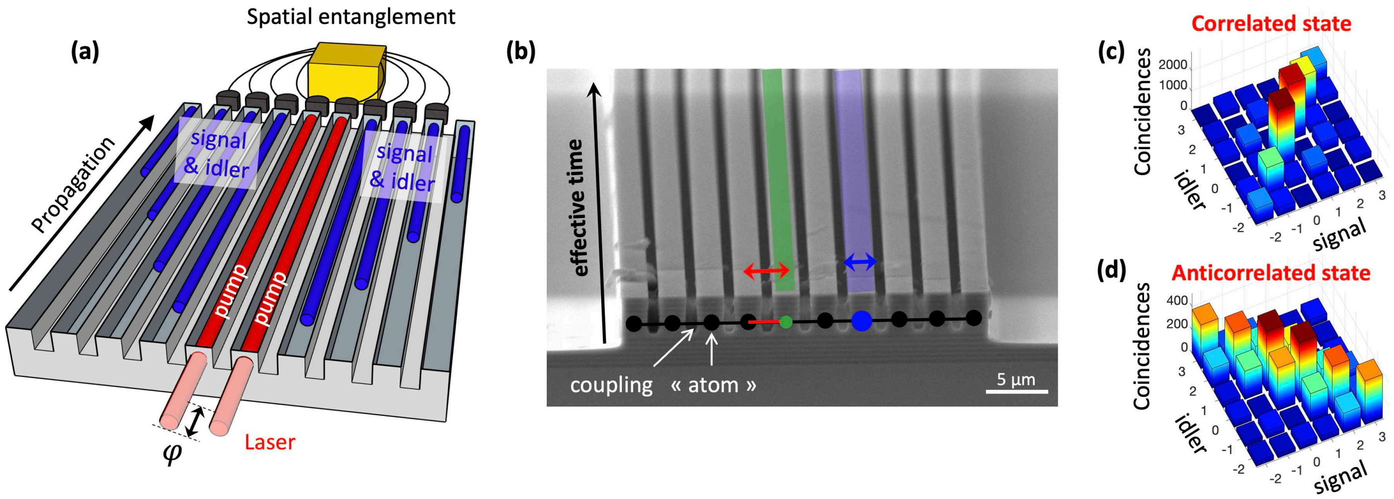
Quantum simulation in waveguide arrays with synthetic dimensions

Quantum physics is opening new pathways for processing and transmitting information, enabling powerful applications in quantum computing, simulation or communication. Photons lie at the core of this revolution, acting as versatile carriers of quantum information. A major current challenge is to **miniaturize** these operations onto a single chip, and to exploit **high-dimensional** quantum states to achieve greater scalability. This internship/PhD project aims to tackle these challenges by using **arrays of nonlinear waveguides** (Fig. 1a-b) fabricated from a well mastered semiconductor platform (AlGaAs) [1,2,3]. A classical pump beam (shown in red) is sent into the device, where it generates photon pairs (shown in blue) thanks to the strong **optical non-linearity** of the material. These photon pairs then jump from one waveguide to the other during their propagation, implementing **random quantum walks**. This results in nontrivial spatial correlations (entanglement) between the photons at the output of the chip (Fig. 1c-d) [2,3].



In addition, waveguide arrays provide a powerful platform for **quantum simulation**. Indeed, they naturally implement a tight-binding Hamiltonian, where discrete sites ("atoms") are linked by tunnel couplings (Fig. 2b). We have recently shown how this can be used to implement 1D topological Hamiltonians and protect photon-pair generation from disorder [4]. The goal of this project is to extend this approach to higher dimensions. To this end, we will harness the concept of **synthetic dimensions**, where internal photonic degrees of freedom of photons emulate additional coordinates, enabling highly versatile realizations of complex Hamiltonians. Specifically, by exploiting the mapping between the propagation direction and an effective time variable, we will **(i)** simulate **Floquet topological insulators** exhibiting anomalous edge modes with no static analog. We will then **(ii)** implement a topological pumping protocol for **robust on-chip transfer of entangled states**, and finally **(iii)** investigate how controlled dynamical disorder can **enhance quantum transport**, turning decoherence into a useful resource for quantum networks. Together, these investigations will establish waveguide arrays with synthetic dimensions as a powerful experimental platform to simulate condensed matter problems in a well-controlled environment, and explore new regimes of light–matter interaction tailored at the microscale.

Context : The student will join a friendly and stimulating research team (both experimental and theoretical) with strong international collaborations, gaining experience in a wide range of experimental techniques including clean-room fabrication, quantum optics experiments, and theoretical modeling/simulations.

[**1**] F. Baboux, G. Moody, S. Ducci, **Optica** 10, 917 (2023)
[**2**] A. Raymond,..., F. Baboux, **Phys. Rev. Lett.** 133, 233602 (2024)
[**3**] A. Raymond,..., F. Baboux, **Optics Express** 33, 45869 (2025)
[**4**] A. Zecchetto,..., F. Baboux, arXiv preprint (2025)

Possibility to go on with a PhD ? Yes
Envisaged fellowship ? QuantEDU Project, DIM QuanTip, …