



04/05/2026 – 19/06/2026

**Title of the project:** Photon localization in the paraxial quantum approximation

**Supervisor(s):** Maxime Federico & Hans-Rudolf Jauslin

Laboratory / Department / Team : ICB, ICQ, DiTeQ

**Collaborations:**

## Summary:

Photons are bosonic quantum excitations of the electromagnetic field, and as such they have intrinsic nonlocal property as characterized by the Knight criterion [1]. This property has further been explored by considering the expectation value of the electromagnetic energy density operator [2,3] and is known to be valid in that case for any state that is composed of a finite number of excitations [4]. Experimentally, there exist many sources that produce on-demand single photons, but most of them achieve to produce states that are propagating either in an optical fiber, or along a particular axis of propagation. Consequently, one expects these type of produced photon states to be paraxial photons for which a formulation of the standard quantum optics theory has been developed [5].

The main objective of this internship is to analyze the nonlocal property of single photons within the quantum paraxial approximation as developed in [5] by considering the expectation value of the electromagnetic energy density operator as it was done for the general case in [3,4]. These results will naturally lead us to analyzing the transition from 3D to 1D models in quantum optics and in particular how one can construct the time-frequency formalism [6] that is used in the development of quantum technologies.

[1] J. M. Knight, J. Math. Phys. **2**, 459 (1961).

[2] I. Bialynicki-Birula, Phys. Rev. Lett. **80**, 5247 (1998).

[3] M. Federico and H.R. Jauslin, Phys. Rev. A **108**, 043720 (2023).

[4] M. Federico, PhD Thesis, UBFC (2024).

[5] I.H. Deutsch and J.C. Garrison, Phys. Rev. A **43**, 2498 (1991).

[6] N. Fabre *et al*, Phys. Rev. A **105**, 052429 (2022).

**Type of project (theory/experiment):** Theory

**Required skills:** Quantum optics