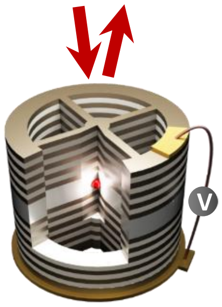
INTERNSHIP PROPOSAL

Laboratory name: **C2N (Center for Nanoscience and Nanotechnology)**
CNRS identification code: **UMR 9001**
Internship director'surname: **LANCO Loïc**
Website: https://quantumdot.eu/
e-mail: loic.lanco@u-paris.fr Phone number: **+33 1 70 27 03 73**
Internship location: **C2N, 10 Boulevard Thomas Gobert, Palaiseau**

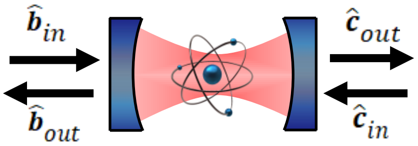
Thesis possibility after internship: **YES**
Potential fundings: **EDPIF and Quant-Edu France**

Theory of atom-photon and spin-photon interfaces: from cavity-QED to waveguide-QED

In the framework of optical quantum computing and communications, a crucial goal consists in **controlling the interaction between single atoms and single photons**. This has first led to the development of cavity-QED, where natural or artificial atoms efficiently interact with confined photons, in an optical or microwave cavity. Many practical demonstrations were also performed in the simplified framework of waveguide-QED, exploiting the direct coupling of atoms to photonic waveguides, fibers, and on-chip photonic circuits.



Our team in C2N has developed quantum-dot-based interfaces which can be used as efficient emitters[1] of single photons: this led to the creation of the company Quandela. A strong challenge remains: **developing quantum nodes that implement quantum logic operations on *incoming* photons**, using the interaction with a single stationary qubit. In such context, we use our light-matter interfaces as efficient *receivers* (and not just emitters) of quantum light: this allowed us, for instance, to demonstrate the first optical nonlinearity triggered at the single-photon level[2]. We also develop spin-photon interfaces[3], with which we could demonstrate the entanglement of a spin with two photons[4], as well as giant polarization rotations induced by a single spin[5].



During the last decade, we have also built a practical theoretical toolbox, allowing to simulate the cavity-QED effects in light-matter interfaces, in excellent agreement with experimental results. By doing so, we realized that a breakthrough can also be obtained on the theory side: **it becomes possible to exactly describe many complex cavity-QED phenomena, with the much simpler framework of waveguide-QED.** This will allow implementing numerical and analytical strategies which were previously out of reach, to invent novel experiments and predict their results.

During this internship, we want to explore the potential of this breakthrough, by numerically demonstrating its full validity, and by extending it to future experiments. In addition to fundamental research, a long-term goal will also be to develop a general, plug & play simulation platform (potentially open-source), that any experimentalist could use to predict the results of complex experiments, with any kind of light-matter interface.

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

---

[1] Somaschi *et al,* **Nature Photonics 10,** 340 (2016); Loredo *et al,* **Nature Photonics 16**, 374 (2022)
[2] De Santis *et al,* **Nature Nanotechnology 12**, 663 (2017)
[3] Arnold *et al,* **Nature Communications 6**, 6236 (2015); Hilaire *et al*, **Physical Review B 102**, 195402 (2020)
[4] Coste *et al,* **Nature Photonics 17**, 582 (2023)
[5] Mehdi *et al*, arXiv:2212.03767 (2022)