**Master 2:** ***International Centre for Fundamental Physics***

## ***INTERNSHIP PROPOSAL***

*Laboratory name*: Laboratoire de Physique des Solides
*CNRS identification code*: UMR8502
*Internship director'surname*: Kociak Mathieu/Tizei Luiz
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*Web page*: https://www.stem.lps.u-psud.fr/
*Internship location*: same as above
*Thesis possibility after internship*: YES
*Funding already obtained for a PhD*: YES *If YES, which type of funding*: European

**Quantum electrodynamics of high finesse cavities with relativistic electrons**

Understanding the interactions between relativistic electrons, matter and optical fields is a vast subject of investigation in physics. Recently, it has received a significant boost of interest. Indeed, the arrival of microscopes allowing the focusing of electrons travelling at half the speed of light on a sub-nanometer area has opened new possibilities in nanooptics. The associated spectroscopies (electron energy loss, cathodoluminescence ...) have suddenly made it possible to measure optical phenomena at unprecedented spatial scales. We can mention for example in our group the three-dimensional and vectorial mapping of phonon modes on the surface of nanoparticles [Li et al., Science 371 1364 (2021)], the demonstration of strong plasmon-phonon coupling at the nanoscale [Tizei et al., Nano Letters, 20, 2973 (2020)], or the visualization of light emission from hybride Perovskyte platelets [Hou et al., Science 374, 621 (2021))]. In these works, while the nanophotonic structures may or may not be quantum, the interaction is well described in a classical way. In parallel, the possibility to inject laser radiation on nanostructures of interest has allowed to reach new coupling regimes between electromagnetic field, relativistic electrons and matter. In a spectacular way, it was recently possible to demonstrate Rabi oscillations for a relativistic electron [Feist et al., Nature 521, 200 (2015)].

It is therefore clear that a new field of investigation is opening up, where it will be possible to perform quantum optics experiments in a cavity with free electrons rather than bound electrons. In this context, we have started to study cavities with high temporal coherence using fast electrons [Auad et al., Nature Communications, 14 4442 (2023)]. In the framework of the European project e-beam and the ANR Quenot, and in collaboration with C2N, we are interested in studying the non-linear effects in cavities related to their very high finesse. We have shown that extremely high finesse cavities made up of defects within photonic band gap materials can couple very efficiently to free electrons [Bézard et al., ACS Nano 18 10417 (2024)].

During this internship, we aim at studying the quantum properties of these cavities under laser illumination. The internship will take place in the solid-state physics laboratory of the University of Paris-Saclay, in the STEM group. The student will benefit from a unique environment for electron spectromicroscopy, in particular through the presence of the Chromatem microscope, and from the help and expertise of the researchers and engineers of the team.

*Applicant skills*: This internship is addressed to a curious student, having the desire to invest in a new field of physics, and liking above all the experimental work. The candidate should have a good level in electromagnetism and quantum mechanics, and a desire to learn about nanooptics.

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

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