INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire de Physique des Solides
CNRS identification code: UMR8502
Internship director'surname: Mathieu Kociak/Luiz Tizei/Odile Stéphan
e-mail:Mathieu.kociak@universite-paris-saclay.fr Phone number:0675345317
Web page: https://equipes.lps.u-psud.fr/stem/
Internship location: Laboratoire de Physique des Solides, bâtiment 510, université Paris-Saclay, Orsay

Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: ERC

Towards entanglement between relativistic electrons and photons mediated by plasmons

Quantum coherence, a cornerstone of modern physics, encompasses phenomena such as quantum entanglement and Rabi oscillations, which have no classical counterparts. Our team aims to push the boundaries of quantum mechanics by leveraging advances in free-electron nanophysics and quantum nano-optics [García de Abajo, F. J. et al. Roadmap for Quantum Nanophotonics with Free Electrons. ACS Photonics 12, 4760–4817 (2025)].

A central open question is whether a relativistic free electron can be entangled with a photon. This internship, which is envisioned as a potential starting point for a PhD project, will focus on addressing this fundamental problem.

To tackle this challenge, we pursue a combined experimental, instrumental, and theoretical approach, designed to measure temporal correlations between a ~100 keV free electron and a photon mediated by a surface plasmon. Specifically, we will use a scanning transmission electron microscope to form a nanoscale electron probe, which we will position with nanometric precision at points of high symmetry in specially engineered chiral plasmonic structures. We have recently demonstrated that such structures emit strongly circularly polarized photons at the energies of their low-energy plasmonic modes. Our preliminary calculations further indicate that in this regime, each electron losing such an energy acquires a well-defined orbital angular momentum [Lourenço-Martins, H., Gérard, D. & Kociak, M. Optical polarization analogue in free electron beams. Nat. Phys. 17, 598–603 (2021)], and becomes almost perfectly entangled with a circularly polarized photon.

To prove this entanglement, we will carry out a series of correlation experiments between electrons and photons, first demonstrated in our team [Varkentina, N. et al. Cathodoluminescence excitation spectroscopy: Nanoscale imaging of excitation pathways. Sci. Adv. 8, (2022).] aimed at testing the violation of the corresponding Bell inequalities. These experiments will rely on a unique worldwide combination of microscope, tailored samples, and state-of-the-art detectors.

The project is embedded within the framework of the ERC FreeQCC and the ANR Bernardo. During the internship, the student will work on the optical setup, participate in the experiments, and contribute to data analysis. This internship is intended for a motivated and curious student with a passion for quantum physics and advanced instrumentation, and a strong desire to explore an entirely new research domain.

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