Ph D Proposal

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Title : 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. In the last twenty years, 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 vector 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 [Houet al., 374 6567 Science (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 light and electrons in parallel 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)]. Then, shortly after its prediction [di Guilio, Kociak & Garcia de Abajo., Optica 6, 1524 (2019)], it was demonstrated that one could directly measure the quantum statistics of a field in a cavity using relativistic electrons [Dahan et al., Science 373, 6561 (2021)].
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.
The main goal of the proposed research is to create and measure Fock states in high finesse cavities. In this aim, we will use unique cavities compatible with the use of relativistic electrons fabricated at the C2N (X. Checoury team). Two different sets of experiments will be performed.
The first set will consist in starting from the ground state of the cavity. The cavity will be populated by a first electron which will lose some energy. Given the record long lifetime of the cavity, a second electron will be able to pick the energy lost by the first one, and get accelerated. Such an acceleration, which has not been yet be detected, will be analyzed to unveil the statistics of a single excitation in the cavity.
The second set will consist in starting from a state where the cavity is filled by one photon. In that case, the energy lost by an electron will also depend on the statistics of the cavity modes.
In both cases, the experiment will rely on a world unique microscope, CHROMATEM, without which the experiments are not possible. The second set of experiments will involve the development of a special sample holder, to which the candidate may be associated.
The analysis of the experiments will require new theoretical development. The lab benefits of a unique collaboration with the theory group of J. Garcia de Abajo (ICFO, Spain), and the candidate may be involved in those developments.
The project will hold in the framework of the ANR QUENOT project, and the European EBEAM project. It will be mainly experimental, and upon the applicant tastes and skills, may include instrumentation and/or theoretical development.
This project is aimed at a student who is curious, likes experimentation but is also very attracted by new concepts in physics within a booming research field.