SCIENCES SORBONNE UNIVERSITÉ

LKB

Master thesis proposal

LKB/ SU, Campus P. et M. Curie (Jussieu)
Director : Nicolas Treps

Title: Theoretical description of quantum electrodynamics in strong fields

Keywords: exotic atoms, bound-state quantum electrodynamics, non-perturbative methods, x-ray spectroscopy

Scientific description: The focus of this internship is the improvement of theoretical methods to describe quantum electrodynamics (QED) in the vicinity of the Coulomb field created by an atomic nucleus with large nuclear charge number *Z*. In contrast to low-*Z* ions, the coupling of the quantum vacuum to the nucleus has to be described non-perturbatively in the high-*Z* regime because of the strong Coulomb field. This non-perturbative description creates additional challenges for theory compared to the perturbative regime, but is necessary to provide accurate theoretical predictions for many ongoing and future experiments that aim to test QED in strong fields.

One of the main tasks will be adapting established methods for the description of electronic ions to exotic systems, where one or more electrons have been replaced by a heavier exotic particle, like a muon or an antiproton. Due to their higher mass, these particles orbit significantly closer to the nucleus than an electron in the same state and probe electric fields that are orders of magnitude larger. State-of-the-art experiments with exotic atoms, such as the PAX (antiProtonic Atom X-ray spectroscopy) experiment currently under development at LKB (Baptista et al. 2025), can test the Standard Model in a regime that is otherwise inaccessible in a laboratory. However, these experiments require more precise theoretical predictions for the transition energies in exotic atoms to fully exploit their potential as precision tests of the Standard Model. Recent developments in the calculation of the two-loop Lamb shift for heavy electronic systems can be applied directly to exotic atoms to reduce remaining sources of theoretical uncertainty.

The present internship will take place at the Pierre et Marie Curie campus in Paris. The knowledge acquired and preliminary work done during the internship will be the starting point of longer-term PhD projects on heavy muonic, antiprotonic and highly charged ions.

Techniques/methods in use: The candidate will become familiar with bound-state quantum electrodynamics, non-perturbative methods, numerical computation, and x-ray spectroscopy

Applicant skills: Knowledge of one or several of the following topics is required: atomic physics, QED, C++, python

Industrial partnership: N

Internship supervisor: Jonas Sommerfeldt, jonas.sommerfeldt@lkb.upmc.fr

Internship co-supervisor: Nancy Paul, npaul@lkb.upmc.fr

Internship location: LKB, Sorbonne Université, 4 place Jussieu, 75005 Paris

Possibility for a Doctoral thesis: Yes (to be financed via the doctoral school)

Synopsis:
This internship will be centred on the theoretical description of corrections from quantum electrodynamics to the energy levels of exotic atoms, where one or more electrons have been replaced by an exotic particle, like a muon or antiproton. The extreme fields present in these systems require a non-perturbative description of the coupling to the Coulomb field of the nucleus.