Laboratoire Kastler Brossel : Proposal for a PhD thesis beginning in 2019

Doctoral School : **N° : EDPIF**

Responsible for the thesis :

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Team : Metrology of simple systems and fundamental tests

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Laser spectroscopy of muonic atoms

The objectives of the experiment are to measure, by means of laser spectroscopy, the ground state (1S) hyperfine splitting (HFS) of muonic hydrogen (μp) and muonic helium (μ^3He^+) with 1 ppm uncertainty. Both atomic lines have never been observed up to now!

These are challenging experiments, which need cryogenic gas target, muon beam line, X-rays detector system with 4π coverage, cutting edge single-frequency high energy pulsed thin-disk laser, optical parametric oscillators and amplifiers and high power multi-pass cavities.

The fundamental science motivations for this project are multi-folded: letting aside the proton radius puzzle [1] [2] [3] and related “new physics” searches, the 1S-HFS in μp and μ^3He^+ measurements impact three aspects of fundamental physics: bound-state QED in H-like systems, our understanding of the low-energy structure of the proton and of the most simple nuclei. The full experiment will be done at Paul Scherrer Institute (Villigen, Switzerland) where a new muon beam line and the first element of the laser chain (thin disk laser) are developed.

The scheme proposed to reach the 6.7 µm need for muonic hydrogen is to use an OPO OPA laser chain to convert the thin disk laser pulse at 1030 nm first to 1785 nm (idler) and 2434 nm (signal), respectively. In a successive difference frequency generation (DFG), the IR pulse at 6.7 µm is produced. The scheme proposed for muonic helium (930 nm) is similar but simpler, as it is in the 1µm region and without the DFG stage. The frequency control of the proposed laser systems will be achieved by seeding the pulsed lasers with cw-lasers. As the relation ship between the various wavelengths is fixed by energy conservation, two cw-lasers are needed to control the frequency at 6.7 µm. Our choice is a cw-laser at 1030 nm seeding the disk-laser running and another one seeding the OPO at 1785 nm. The frequency of the 1030 nm laser is fixed while the one of the 1785 nm is tunable in order to scan the IR frequency at 6.7µm. For the helium spectroscopy, the seeded lasers will be the one at 1030 nm and the idler at 930 nm.

The PhD work proposed will consist in developing the cw-laser at 1785 nm, 1030 nm and 930 nm (2019-2020), participate to the development of the OPO OPA chain (2019-2020) and to the data taking at PSI (2020-2021). The frequency stabilization at 930 nm and 1785 nm will be achieved by locking these lasers to commercial wavemeters. The frequency of the laser at 1030 nm will be stabilized at 515 nm on iodine molecule after a second harmonic generation (SHG) stage. These lasers will be then installed at PSI, where the PhD student will participate to the development of the pulsed OPO OPA chain and the search of the first atomic line.

[1] R. Pohl, A. Antognini, F. Nez *et al*, Nature **466**, 213-216 (2010)
[2] A. Antognini, F. Nez,… R. Pohl, Science **339**, 417 (2013)
[3] R. Pohl, F. Nez, … A. Antognini, Science **353**, 669 (2016)

Required skills:

The work proposed during this PhD thesis is mainly experimental. The candidate is expected to have some expertise in techniques used in atomic physics (laser, vacuum, electronics,...). Theoretical knowledge of the basics of atomic physics is also necessary. This work is done in the frame of an international collaboration, English speaking and writing is required.