Cw laser spectroscopy of the 1S-3S transition in hydrogen: new contribution to the proton radius puzzle

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High resolution spectroscopy of the hydrogen atom plays a key role in testing the theory of quantum electrodynamics, and in the determination of fundamental constants, such as the Rydberg constant or the proton charge radius. Since 2010, a disagreement has been found between the proton radius deduced from the spectroscopy of muonic hydrogen [1] and the CODATA-recommended value [2] relying on experiments conducted on electronic hydrogen (Fig. 1). To date still unsolved, this *proton radius puzzle* was even recently deepened by two new contradictory results in hydrogen spectroscopy: the 2S-4P transition frequency measured at MPQ [3], and the 1S-3S transition frequency measurement presented here.

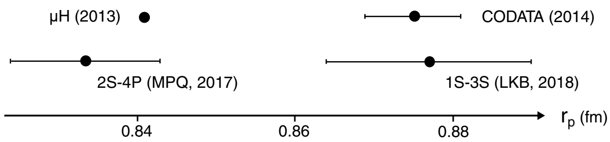

Figure 1: Proton charge radius values from hydrogen spectroscopy, with 1σ error bars.

In our experiment, the 1S-3S transition of atomic hydrogen is excited by two counter-propagating photons at 205 nm, in a Fabry-Perot cavity inside a vacuum chamber. An effusive beam of ground state hydrogen atoms at room temperature is directed colinearly with the axis of the cavity. We observe the 1S-3S resonance by detecting the Balmer α fluorescence at 656 nm. We use sum frequency generation in a BBO cristal to produce the cw laser source at 205 nm, by mixing a Ti:Sa laser at 894 nm and a frequency doubled Verdi laser at 532 nm. Their frequencies are measured using an optical frequency comb referenced to the LNE-SYRTE primary frequency standards thanks to a 3-km-long fiber link.

The main systematic effect to be considered is the second-order Doppler shift. It is corrected by fitting our experimental data with theoretical lineshapes taking into account the velocity distribution of the atoms in our effusive beam. This velocity distribution is determined by measuring the shift of the transition frequency when a transverse magnetic field is applied to the moving atoms, inducing a motional quadratic Stark effect [4]. Other systematic effects include a collisional shift, an AC Stark shift, and a recently evaluated quantum interference effect [5]. The overall uncertainty on the 1S-3S transition frequency is 2.6 kHz, that is a relative uncertainty of 9×10^{-13}. It yields a value of the proton radius that appears to support the CODATA-recommended value [6].

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[5] H. Fleurbaey *et al.*, Phys. Rev. A **95** (2017) 052503.
[6] H. Fleurbaey *et al.*, arXiv:1801.08816 (2018).