Muonic Hydrogen and the Proton Radius Puzzle

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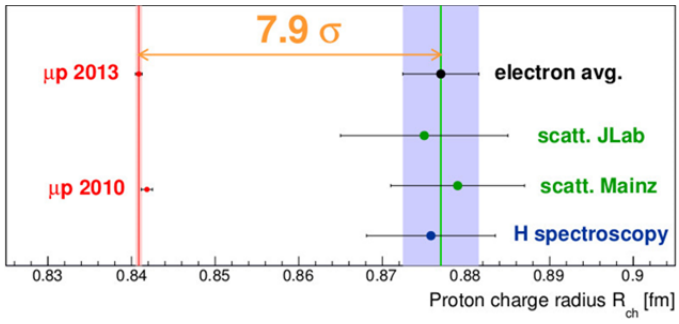
Muonic atoms and ions are hydrogen-like systems that are formed when negative muons are stopped in ordinary matter, thereby replacing all of the atom's electrons by a single muon. The muon's Bohr radius is 200 times smaller than the corresponding electronic Bohr radius in ordinary H-like ions, due to the 200 times larger mass of the muon, compared to the electron. This results in a tremendously increased sensitivity (200^3) of the muonic atom's S-states to the finite charge and magnetic radius of the nucleus.

We have recently determined the proton charge radius by laser spectroscopy of the Lamb shift (2S-2P transition) in muonic hydrogen (μp) [1][2]. Our value of R_p=0.84087(39) fm is ten times more accurate, but 7 sigma discrepant from the world average, which is based on elastic electron-proton scattering and precision spectroscopy of regular (electronic) hydrogen[3] (see Fig.).



This so-called "proton radius puzzle" has sparked tremendous interest both in atomic and nuclear physics. Possible explanations range from experimental errors to unexpected behavior of the proton and to physics beyond the Standard Model[4].

To shed new light on this discrepancy, we have measured the Lamb shift in muonic deuterium and extracted a value of the charge radius of the deuteron. Last year we've also measured the Lamb shift in muonic helium ions. This will improve the accuracy of the charge radii of all helium isotopes by a factor of ten[5]. In future, spectroscopy of of muonic lithium, beryllium and boron ions may be used for significantly improved charge radius value of the lightest isotopes[6].

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1 R. Pohl et al. (CREMA coll.), "The size of the proton", Nature 466, 213 (2010).

2 A. Antognini et al. (CREMA coll.), "Proton structure from the measurement of 2S-2P transition frequencies of muonic hydrogen", Science 339, 417 (2013).

3 P.J Mohr, B.N. Taylor, D. Newell, "CODATA recommended values of the fundamental physical constants: 2010", Rev. Mod. Phys. 84, 1527 (2012).

4 R. Pohl et al., "Muonic hydrogen and the proton radius puzzle", Ann. Rev. Nucl. Part. Sci 63, 175 (2013).

5 A. Antognini et al. (CREMA coll.), "Illuminating the proton radius conundrum: the μHe^+ Lamb shift", Can. J. Phys. 89, 47 (2011).

6 G.W.F. Drake, L.L. Byer, "Lamb shifts and fine-structure splittings for the muonic ions: μ^- Li, μ^- Be, and μ^- B: A proposed experiment", PRA 32, 713 (1985).