the proton radius conundrum

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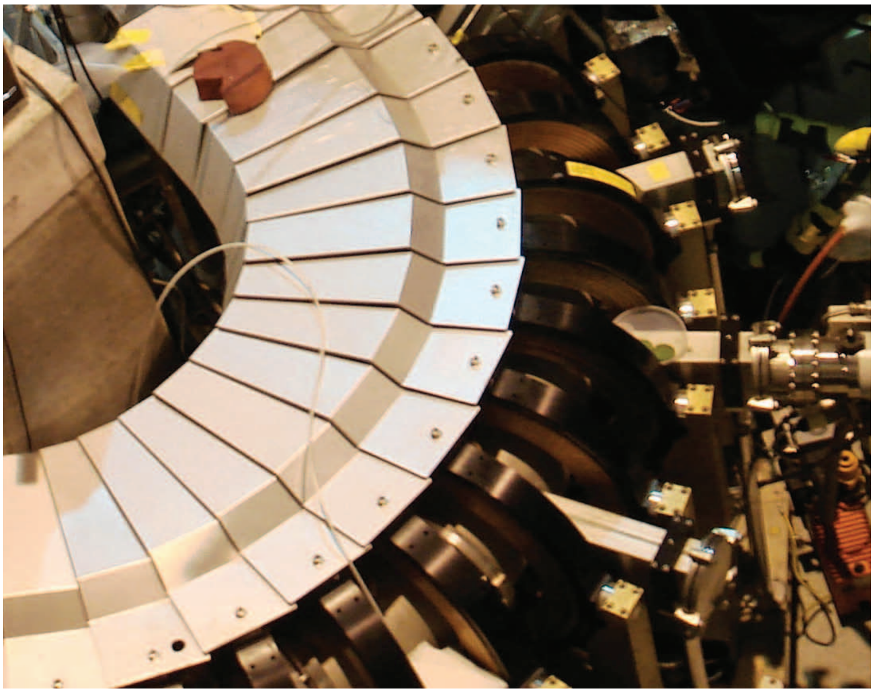

Being the simplest atom, hydrogen has been intensively studied during the past century and used as the ideal playground to test the foundations of physics. Therefore it has been regarded as the "Rosetta Stone" of quantum physics as many answers were reached from its intense study.
An idea to deduce the proton radius by means of hydrogen laser spectroscopy was born in the early seventies. Muonic hydrogen would be used instead of atomic hydrogen. About 200 times heavier, the negative muon should orbit about 200 times closer to the proton. Hence, the influence of the proton on the atomic energy levels of the muon should be magnified. The unprecedented accuracy of the method was expected to put QED to the test as QED can relate the proton radius to the hydrogen Lamb-shift - the transition energy aimed to be directly measured. Nevertheless, such measurement took about 40 years to be accomplished due to the overwhelming technical difficulties involved and it was only possible due to the joint effort of 32 scientists from 3 continents in which each team has brought its own expertise in the fields of accelerator physics, atomic physics, laser technologies and detectors.

One of those technical difficulties was the development of a suitable X-ray detector system. The task was realized through the main contribution from the Portuguese team which includes the I3N-Aveiro researchers, Prof. João Veloso and Dr. Daniel Covita, and it renders to be crucial to achieve the experimental success, a success that only arrived on the evening of July 5 2009, after three unsuccessful runs (2002, 2003 and 2007), and following 3 months of set up time and three weeks of continuous data taking (day and night).

The experiment was performed at the πE5 beam-line of the proton accelerator at PSI (see photo). An intense and low-energy muon beam (~5 keV kinetic energy) was generated and injected into a hydrogen target at low pressure (1 hPa). The muons are stopped in the hydrogen gas forming highly excited muonic hydrogen ($n \approx 14$) which quickly de-excite to ground state (1S). However, a small fraction ends up at the long-lived (metastable) 2S state.
A set of detectors produces a trigger signal each time a muon enters the hydrogen target and allows the tunable laser system to be fired into the hydrogen target. If the laser pulse matches the Lamb-shift energy it will induce the muon transition to an upper level (2P). Once in the 2P state, the muon decays rapidly to the ground state with the emission of an X-ray photon detected by the X-ray detector system placed around the hydrogen target. The temporal coincidence between the trigger signal, the laser shoot, and the 2P-1S characteristic X-ray, inside a very narrow time window separates a good event from background. By tuning the laser to scan the region around the transition energy over many repetitions, a resonance spectral line was obtained which allowed a very accurate measurement of the muonic hydrogen Lamb-shift.

After a long and careful analysis of this signal, the deduced value of the proton radius turned to be ten times more precise, 0.84184 femtometers (1 femtometer = 0.000 000 000 000 001 meter), but in strong disagreement with the accepted value (0.8768 femtometers). This unexpected difference of about 4% is huge in the QED framework and discussions on possible reasons to explain it are still ongoing. There are several aspects which are under scrutiny by now: previous high-precision measurements, extended and intricate calculations involved and maybe at some point even small readjustments to the world's most precise and best-tested fundamental theory itself – quantum electrodynamics. The conundrum is set and further developments from experimental and theoretical work are awaited.

It is rather remarkable that hydrogen spectroscopy continues to challenge our understanding of physics, as it has done over the past 100 years. And if experimental discrepancies are confirmed, more remarkable will be that this high-accuracy experiment may have seen beyond the standard model of particle physics before the high-energy giant colliders. By now, the proton radius conundrum is one of the hottest topics of physics as it proves the recent 9th position of our collaboration in the top 10 breakthroughs of 2010 selected by the *Institute of Physics* (IOP) or the fact of its related *Nature* publication, [*Nature*, 466(2010)213, cover of the issue] being the most downloaded paper in August 2010 from the *Nature* website.