Report on

The MITP Proton Radius Puzzle Workshop

June 2–6, 2014 in Waldthausen Castle, Mainz, Germany

1 Description of the Workshop

The organizers of the workshop were:

- Carl Carlson, William & Mary, carlson@physics.wm.edu
- Richard Hill, University of Chicago, richardhill@uchicago.edu
- Savely Karshenboim, MPI für Quantenoptik & Pulkovo Observatory, sek@mpq.mpg.de
- Marc Vanderhaeghen, Universität Mainz, marcvdh@kph.uni-mainz.de

The web page of the workshop, which contains all talks, can be found at
https://indico.mitp.uni-mainz.de/conferenceDisplay.py?confId=14 .

The size of the proton is one of the most fundamental observables in hadron physics. It is measured through an electromagnetic form factor. The latter is directly related to the distribution of charge and magnetization of the baryon and through such imaging provides the basis of nearly all studies of the hadron structure.

In very recent years, a very precise knowledge of nucleon form factors has become more and more important as input for precision experiments in several fields of physics. Well known examples are the hydrogen Lamb shift and the hydrogen hyperfine splitting. The atomic physics measurements of energy level splittings reach an impressive accuracy of up to 13 significant digits. Its theoretical understanding however is far less accurate, being at the part-per-million level (ppm). The main theoretical uncertainty lies in proton structure corrections, which limits the search for new physics in these kinds of experiment.

In this context, the recent PSI measurement of the proton charge radius from the Lamb shift in muonic hydrogen has given a value that is a startling 4%, or 5 standard deviations, lower than the values obtained from energy level shifts in electronic hydrogen and from electron-proton scattering experiments, see figure below.

The interpretation of this discrepancy is at present a wide open issue. To extract the proton charge radius from the muonic hydrogen Lamb shift result, the form factors, proton structure functions and polarizabilities are required as input in a quantitative understanding of the hadronic corrections. The precise knowledge of such corrections is also imperative before interpreting the muonic Lamb shift discrepancy as a harbinger of new physics, as speculated in recent papers.

The Proton Radius Workshop was organized to bring the atomic, hadron, and particle physics communities together to discuss the new experiments that have been motivated by the puzzle, and to discuss the hadronic corrections required to interpret the atomic physics experiments. Furthermore, it also discussed the different scenarios of new physics and old physics which have been proposed as an explanation of the discrepancy.

Some of the more specific topics presented in talks at the workshop, grouped under several headings, were

1. Theory support for data analysis
   - Dispersion theory analyses of e-p scattering data
   - Fits to the form factors using analytic remapping

- Higher order corrections, in particular two photon corrections in e-p scattering
- Polarizability corrections in light nuclei

2. Beyond Standard Model Explanations
   - Constraints
   - Low-mass possibilities for new particles
   - Extended new particle analysis
   - Unexpected QCD behavior

3. Experimental future
   - Proton charge radius experiment: the muon scattering experiment at PSI (MUSE)
   - Proton charge radius experiment: new electron scattering experiments at low Q^2 at Jefferson Lab
   - Proton charge radius experiment: new electron scattering experiments at low Q^2 at MAMI
   - Precision atomic spacings in ordinary hydrogen, in particular the $2S$-nP, the $1S$-$3S$, and S-state hyperfine splittings.
   - Precision Lamb shift
   - Heavier atom muonic Lamb shift
   - Deuteron form factors and deuteron charge radius at MAMI

Perhaps the highlights of the conference were the new data, publicly presented for the first time, on the Lamb shift in muonic Helium-4, and presentation of the several experiments that, in June 2014, held out the promise of data being publicly delivered before the end of calendar 2014. These included the three precision atomic spacing experiments in ordinary hydrogen, plus the initial state radiation experiment at MAMI that would give proton form factors at very low Q^2. In addition, there were a number of theory talks that publicly presented new form factor analyses and new higher order corrections. Also, the surprising result that the Helium muonic Lamb shift shows no discrepancy while it Hydrogen equivalent does has already spawned new theoretical work.

We acknowledge the support of the PRISMA Cluster of Excellence, the Mainz Institute for Theoretical Physics MITP, and the Deutsche Forschungsgemeinschaft DFG through the Collaborative Research Center "The Low-Energy Frontier of the Standard Model" (SFB 1044). Websites for the MITP and the SFB 1044 may be found at [http://www.mitp.uni-mainz.de] and [http://sfb1044.kph.uni-mainz.de/sfb1044/].

2 List of participants

- Constantia Alexandrou, University of Cyprus, alexand@ucy.ac.cy
- Aldo Antognini, ETH Zurich, aldo.antognini@psi.ch
- Jan Bernauer, Massachusetts Institute of Technology bernauer@mit.edu
- Axel Beyer, Max-Planck-Institut für Quantenoptik, axel.beyer@mpq.mpg.de
- Michael Birse, Manchester University, mike.birse@manchester.ac.uk
- Edith Borie, Karlsruhe Institute of Technology, e.borie@ieee.org
- Carl Carlson, William & Mary, carlson@physics.wm.edu
- Kees de Jager, Jefferson Lab, kees@jlab.org
- Michael Distler, Universität Mainz, distler@uni-mainz.de
- Evie Downie, George Washington University, edownie@gwu.edu
- Haiyan Gao, Duke University, gao@phy.duke.edu
- Ron Gilman, Rutgers University, rgilman@physics.rutgers.edu
- Mikhail Gorshteyn, Universität Mainz, gorshtey@kph.uni-mainz.de
- Keith Griffioen, William & Mary, griff@physics.wm.edu
- Erik Hessels, York University, hessels@yorku.ca
- Richard Hill, University of Chicago, richardhill@uchicago.edu
- Ulrich Jentschura, Missouri University of Science and Technology, ulj@mst.edu
- Savely Karshenboim, MPI für Quantenoptik & Pulkovo Observatory, sek@mpq.mpg.de
- Michael Kohl, Hampton University, kohlm@jlab.org
- Franz Kottman, ETH Zurich, franz.kottmann@psi.ch
- Gabriel Lee, University of Chicago, leeg@uchicago.edu
- Ina Lorenz, University Bonn, lorenzi@hiskp.uni-bonn.de
- Miha Mihovilovic, Universität Mainz, miham@kph.uni-mainz.de
- Gerald Miller, University of Washington, miller@phys.washington.edu
- Nir Nevo Dinur, The Hebrew University, Jerusalem, nir.nevo@mail.huji.ac.il
- Francois Nez, Laboratoire Kastler Brossel, francois.nez@lkb.upmc.fr
- Vladimir Pascalutsa, Universität Mainz, vladipas@googlemail.com
- Gil Paz, Wayne State University, gilpaz@wayne.edu
- Randolf Pohl, Max-Planck-Institute of Quantum Optics, randolf.pohl@mpq.mpg.de
- Thomas Rae, Universität Mainz, rae@kph.uni-mainz.de
- Ben Rislow, Universität Mainz/Ellsworth Community College, Ben.Rislow@iavalley.edu
- Ingo Sick, University Basel, Ingo.Sick@unibas.ch
- Oleksandr Tomalak, Universität Mainz, tomalak@uni-mainz.de
- Marc Vanderhaeghen, Universität Mainz, marcvdh@kph.uni-mainz.de