# FOCAL x-ray precision spectroscopy at ESR

Heinrich F. Beyer

h.beyer@gsi.de — http://mac02.gsi.de

Gesellschaft für Schwerionenforschung (GSI), Planckstraße 1
D-64291 Darmstadt, Germany

Inner electrons of atoms with a high nuclear charge are exposed to very strong electric fields leading to a considerable part of their binding energy being determined by quantum-electrodynamic (QED) processes. Despite its great success for light particles and bound systems like atomic hydrogen the QED theory is *less* well tested for electrons in very strong fields. For a sensible test the strong Coulomb fields of the heaviest hydrogen-like systems like $Au^{78+}$ or $U^{91+}$ are required. The effects are accessible via x-ray spectroscopy of electronic transitions into the deepest states, in particular the 1*s* ground state of hydrogen-like ions.

Previously, such measurements were carried out at the electron cooler [1] and at the gas jet [2] of the Experimental Storage Ring (ESR) at GSI employing solid-state Ge(i) detectors. The combined accuracy of these experiments is limited to $\pm 10$ eV for the 1*s* Lamb shift of uranium. On the theoretical side much progress has been made over the last decade resulting in a claimed uncertainty near $\pm 2$ eV [3].

In order to improve the experimental accuracy, a spectral resolving power is needed that exceeds the one achievable with Ge(i) detectors. On the other hand, employing high-resolution instruments of naturally low sensitivity puts high demands on the usable source strength. A way out of the conflict between accuracy and sensitivity may be shown by new optimized x-ray optics.

The new x-ray optics [4], set up in the **FO**cussing **C**ompensated **A**symmetric **L**aue (**FOCAL**) geometry, will aid in achieving an accurate determination of binding energies of heavy hydrogen-like ions in the ESR storage ring. The spectrometer, serves in measuring small wavelength differences between the fast moving x-ray source, represented by the circulating ions in the ESR, and a stationary calibration source. It is designed for energies between 50 and 100 keV or wavelengths between 25 and 12 pm leading to Bragg angles of less than $4^\circ$ for a Si(220) crystal. With this scheme a favorable detection efficiency is obtained preserving a high systematic wavelength accuracy for both fast moving and stationary x-ray sources. A prototype of such an instrument was built and first tests have been performed. In these tests [5] the FOCAL spectrometer was either operated in scanning mode with a movable slit in front of a conventional Ge(i) detector or a new germanium strip detector was installed that is presently under development [6].

Since its commissioning the ESR has shown a continued and impressive increase in its average x-ray photon flux which is determined by quantities like the speed of filling with ions, cooling times plus time constants for moving scrapers and particle detectors. Given the present performance of the ESR and the improved design of the new crystal spectrometers precision and accuracy goals can be achieved.

The Lamb-shift experiments employing FOCAL are performed in an international collaboration.

## Literature


[1] H.F. Beyer, G. Menzel, D. Liesen, A. Gallus, F. Bosch, R.D. Deslattes, P. Indelicato, Th. Stöhlker, O. Klepper, R. Moshammer, F. Nolden, H. Eickhoff, B. Franzke, and M. Steck, *Measurement of the Ground-State Lamb Shift of Hydrogen-Like Uranium at the Electron Cooler of the ESR*, Z. Phys. D **35** (1995) 169.

[2] T. Stöhlker, P. H. Mokler, F. Bosch, R. W. Dunford, B. Franzke, O. Klepper, C. Kozhuharov, T. Ludziejewski, F. Nolden, H. Reich, P. Rymuza, Z. Stachura, M. Steck, P. Swiat, and A. Warczak, *1s Lamb Shift in Hydrogenlike Uranium Measured on Cooled, Decelerated Ion Beams*, Phys. Rev. Lett. **85** (2000) 3109.

[3] T. Beier, P.J. Mohr, H. Persson, G. Plunien, M. Greiner, and G. Soff, *Current Status of Lamb-Shift Predictions for Heavy Hydrogen-Like Ions*, Phys. Lett. A **236** (1997) 329.

[4] H.F. Beyer, *Characterization of Transmission-Type Curved-Crystal X-Ray Optics for Fast Ion-Beam Spectroscopy*, Nucl. Instrum. Methods. A **400,** (1997) 137.

[5] H.F. Beyer, J. Bojowald, G. Borchert, F. Bosch, W. Brüchle, M. Czanta, R.D. Deslattes, E. Förster, A. Freund, A. Gumberidze, A. Hamacher, J. Hoszowska, P. Indelicato, H.-J. Kluge, Chr. Kozhuharov, D. Liesen, B. Lommel, T. Ludziejewski, X. Ma, B. Manil, I. Mohos, D. Protić, A. Simionovici, Th. Stöhlker, C. Strietzel, S. Toleikis, N. Trautmann, J. Tschischgale, A.H. Walenta, O. Wehrhan, *Progress in the Optimization of the FOCAL Crystal Spectrometer*, in: GSI Scientific Report 2000.

[6] D. Protić, T. Stöhlker, H. F. Beyer, J. Bojowald, G. Borchert, A. Gumberidze, A. Hammacher, C. Kozhuharov, X. Ma, and I. Mohos, *A Micro-Strip Germanium Detector for Position-Sensitive X-Ray Spectroscopy*, IEEE Trans. Nucl. Science (2000).