

# Sub-Femtosecond Correlated Dynamics Probed with Antiprotons

J. Ullrich, M. Grieser, R. von Hahn, K.U. Kühnel, R. Moshhammer, C.D. Schröter,  
C.P. Welsch

*Max-Planck Institute for Nuclear Physics, Germany*

Whereas the three-body Coulomb problem for single excitation and ionization has claimed to be solved for the first time in a mathematically correct way during 1999 until 2004 for electron impact on hydrogen and helium, ion-impact ionization still represents a major challenge for theory. Troubling discrepancies have been observed recently in fully differential cross sections (FDCS) for He single ionization by fast ion impact and even experimental total cross sections are in striking disagreement with the predictions of all state-of-the-art theories for low-energy antiproton collisions.

For antiprotons at energies below about 300 keV down to 1 keV the interaction time between the projectile passing atoms or molecules is on the order of 80 attoseconds (as) up to 1 femtosecond (fs) and, thus, comparable to the revolution time of outer-shell electrons in atoms or molecules. Since ionization or excitation is the only reaction channel that can occur for antiprotons, and electron energies would be below the threshold at similarly low velocities, slow antiprotons provide an unsurpassed, precise and the only tool to study many-electron dynamics in the strongly correlated, non-linear, sub-femtosecond time regime, the most interesting and, at the same time, most challenging domain for theory.

Exploiting and developing many-particle imaging methods – reaction-microscopes – in combination with novel electrostatic storage rings for slow antiprotons we envision to perform, for the first time, single and multiple ionization cross section measurements for antiprotons colliding with atoms, molecules and clusters. Total, as well as any differential cross sections up to FDCS including ionization-excitation reactions will become available serving as benchmark data for theory. Several theory groups world wide concentrate efforts to solve the fundamental few-body Coulomb problem for heavy-particle and antiproton impact. Moreover, the formation of antiprotonic atoms, molecules or of protonium might be explored in kinematically complete experiments at ultra-low energies yielding unprecedented information on  $(n, l)$ -distributions of captured antiprotons as well as precise spectroscopic data of the respective energy levels.

In order to achieve these goals, challenging developments in both, storing and imaging techniques have been launched at MPI-K. A novel ultra-low energy storage ring (USR) to be integrated at the proposed facility for low-energy antiproton and ion research (FLAIR) will be developed for electron-cooled antiprotons in the energy range between 300 keV and 20 keV possibly even approaching the sub keV regime. A reaction microscope shall be integrated in the ring thus achieving unprecedented luminosity. Recently a fully equipped in-ring reaction microscope has been operated for the first time successfully in the Experimental Storage Ring (ESR) at GSI and is now further improved at the Test Storage Ring (TSR) in Heidelberg.

In the talk, the present status of experiments in comparison with theory will be highlighted and the layout of envisioned machines at FLAIR, the USR with an integrated as well as single-pass reaction microscope, will be presented.