Conclusions from recent pionic–atom experiments

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A precise method to determine the low–energy pion–nucleus interaction is to measure the level shift and broadening by means of ultimate–resolution X–ray spectroscopy. The techniques developed together with an underlying low–energy approach of QCD – chiral perturbation theory – allow the extraction of strong–interaction quantities at the per cent level [1]. The ground–state level shift and broadening in pionic hydrogen are directly related to fundamental parameters of the pion–nucleon interaction, the isospin scattering lengths $a^{\pm}$ and the πN coupling constant. Constraints on these scattering lengths are obtained from a measurement of pionic deuterium level shift. The deuterium level broadening provides an independent access to s–wave pion absorption and production on nucleon pairs. The build up of the pion's interaction with few nucleon systems is studied in measurements of the helium isotopes.

The experiments were performed at the Paul Scherrer Institut (PSI), Switzerland, using a high–resolution crystal spectrometer equipped with a large–area CCD array for position–sensitive X–ray detection. The cyclotron trap II provides a high stop density which is essential for an efficient formation of exotic atoms. Several measurements at various target densities and for different X–ray transitions have been performend in pionic hydrogen and deuterium to quantify or identify cascade effects, which must be considered for an unambiguous extraction of the hadronic effects. Data taking has been supplemented by a study of muonic hydrogen in order to determine directly the Doppler broadening from the acceleration of exotic hydrogen during the atomic cascade (Coulomb de–excitation) which hinders the direct extraction of the hadronic broadening from the line width citepsas2006.

Because of the absence of suitable X–ray standards in the few keV range, a new approach was used for the determination of the spectrometer response. With a dedicated electron cyclotron resonance ion trap (ECRIT) [3] narrow X–rays from helium–like argon, chlorine, and sulphur have been produced at high rate, which allows a precise characterisation of the spherically bent Bragg crystals.

First results from the pionic–atom experiments are presented. The techniques are briefly discussed in view of the forthcoming low–energy antiproton facilty FLAIR. There, similar experimental techniques may be applied to antiprotonic atoms in order to extract hadronic affects unambiguously at a level of accuracy comparable to the achievements in pionic atoms.

[1] PSI experiment R–98.01, http://www.fz-juelich.de/ikp/exotic-atoms.

[2] D. Gotta *et al.*, *Proc. of PSAS 2006*, Venice, Italy, Lec. Notes Phys. **745**, 165 (2008).

[3] D. F. Anagnostopoulos *et al.*, Nucl. Instr. Meth. A **545**, 217 (2005).