Precision measurements on kaonic hydrogen and kaonic deuterium: present and future

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Abstract. The DEAR (DAΦNE Exotic Atom Research) experiment performed the most precise measurement ever obtained on the energy of the x rays emitted in the transitions to the ground state of kaonic hydrogen. The results of this measurement are reported in the present paper. The DEAR scientific programme will be continued by the SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) experiment.

INTRODUCTION

The DAΦNE [1] electron-positron collider at the Frascati National Laboratories has made available a unique "beam" of negative kaons providing so unprecedented conditions for the study of the low-energy kaon-nucleon interaction, a field still largely unexplored.

The DEAR (DAΦNE Exotic Atom Research) experiment [2] at DAΦNE and its successor SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) [3] aim at a precision measurement of the strong interaction shift ε and width Γ of the fundamental $1s$ level, via the measurement of the x-ray transitions to this level, for kaonic hydrogen and kaonic deuterium. The goal is to extract the isospin dependent antikaon-nucleon scattering lengths and to contribute to the understanding of aspects of chiral symmetry breaking in the strangeness sector.

Until the advent of DAΦNE, the kaonic hydrogen parameters were measured at KEK [4], where the following results were found:

$$\varepsilon = -323 \pm 63\ (stat.) \pm 11\ (sys.)\ eV; \ \ \Gamma = 407 \pm 208\ (stat.) \pm 100\ (sys.)\ eV \tag{1}$$

This measurement showed clearly that the antikaon-nucleon interaction is of repulsive type, but cannot be considered a precision measurement. The challenging aim of the DEAR/SIDDHARTA experiment is therefore to measure the kaonic hydrogen transitions with a precision at the eV level. The kaonic deuterium will be measured for the first time. These results will represent a breakthrough in the study of the low-energy antikaon-nucleon interaction.

In Section 2, the experimental results on kaonic hydrgen obtained by DEAR are reported, while in the third one the new coming SIDDHARTA experiment is presented.

DEAR RESULT ON KAONIC HYDROGEN

The principle of the DEAR experiment is straightforward: low-momentum negative kaons produced in the decay of the ϕ-mesons at DAΦNE leave the thin-wall beam pipe, are degraded in energy to a few MeV, enter a gaseous target through a thin window and are finally stopped in the gas. The stopped kaons are captured in an outer orbit of the gaseous atoms, thus forming the exotic kaonic atoms. The kaons cascade down and some of them will reach the ground state emitting x rays. The energy of the x rays emitted in these transitions is measured with a CCD (Charge-Coupled Device) detector system [5]. More details on the setup can be found in [6]. For the kaonic hydrogen measurement the target was used with hydrogen at 2 bar and 25 K, corresponding to a density of 2.1 g/l.

Data for 58.4 pb^{-1} of integrated luminosity for kaonic hydrogen were collected in the last months of 2002. At the end of the period, a background measurement with separated electron and positron beams and intentionally high x-ray background was performed (no-collision spectrum).

Two independent analyses were performed in order to obtain the kaonic hydrogen lines from which to extract the strong interaction shift and width. In both analyses Voigt functions with Gaussians for the detector resolution were used for the kaonic hydrogen lines. Fit parameters were the intensities of K_α, K_β and K_γ, the energy of K_α and the Lorentzian width for K_α, equal for all the K-transitions.

Apart from kaonic hydrogen transitions, there are lines coming from the excitation of materials (electronic x-ray transitions) present in the setup. A thin Titanium foil was placed on the upper wall of the target cell for calibration purposes. Other materials - Iron, Zinc, etc. - are present in very small quantities (ppm) in the materials of the setup.

The kaonic hydrogen continuous and structured background subtracted spectrum is shown in Fig. 1.

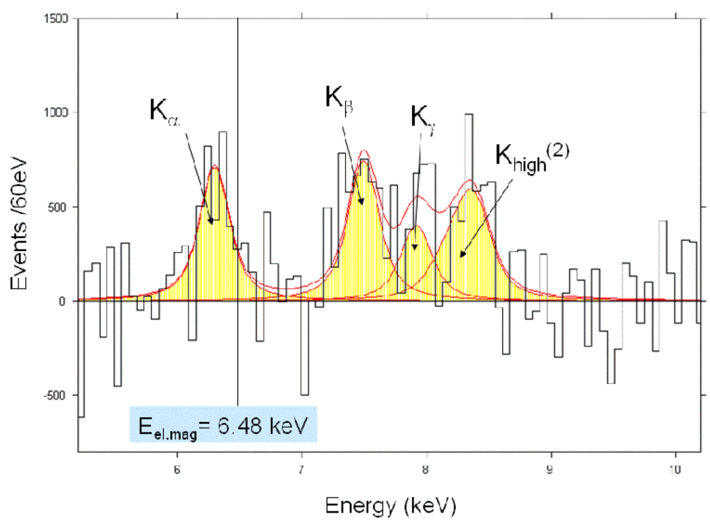

FIGURE 1. *The kaonic hydrogen background subtracted spectrum*

The weighted averages of the two analyses for the shift and width of the 1s ground state of kaonic hydrogen are:

$$\varepsilon = -193 \pm 37(stat.) \pm 6(syst.)\ eV; \ \ \Gamma = 249 \pm 111(stat.) \pm 39(syst.)\ eV \qquad (2)$$

These results confirm the KEK values and the repulsive character of the $K^- p$ interaction at threshold. They differ however significantly from the KEK results (eq. (1)) in two aspects: the errors are a factor 2-3 smaller; moreover, DEAR was able, for the first time, to obtain a full pattern of the K-series lines of kaonic hydrogen: K_α, K_β and K_γ were clearly identified with an overall statistics significance of 6.2 σ.

FUTURE PERSPECTIVES: THE SIDDHARTA EXPERIMENT

DEAR has performed the most precise measurement of kaonic hydrogen. The DEAR precision was limited by a signal/background ratio of about 1/70. In order to go beyond this ratio a jump of quality is necessary.

A new detector was then identified, which preserves all the good features of the CCDs (resolution, linearity and stability) but is fast enough to supply a trigger at the level of one μs. It was estimated to cut in such way the background present in DEAR by 2-3 orders of magnitude. The detector is the newly developed large area Silicon Drift Detector (SDD), based on which a new experiment, which continues the DEAR scientific line, was born. The new experiment is SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) [3].

Presently, construction and testing of the SDD detectors and of the electronics and mechanical structures are in progress. The setup will be installed at DAΦNE in 2006 and start taking data for kaonic hydrogen and kaonic deuterium. These results will open new windows in the study of the kaon-nucleon interaction.

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