Experimental Studies on Kaonic Atoms at DAΦNE: Recent Results and Perspectives

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Abstract.
The DEAR (DAΦNE Exotic Atom Research) experiment and the successor SIDDHARTA (Silicon Drift Detectors for Hadronic Atom Research by Timing Application) are using precision X-ray spectroscopy of kaonic hydrogen atoms to determine the strong interaction induced shift and width of the ground state. From the kaonic hydrogen and kaonic deuterium shifts and widths the isospin-dependent antikaon-nucleon scattering lengths can be determined, thus contributing to the understanding of chiral symmetry breaking in the strangeness sector.

The experimental method of the DEAR experiment and the final results of the kaonic atom studies are presented, i.e. the first measurement of three X-ray transitions of kaonic nitrogen and the most precise measurement of the strong interaction caused shift and width in kaonic hydrogen obtained up to now.

An outlook to the next steps of the experimental program will be given.

Keywords: kaonic hydrogen atom, kaon-proton strong interaction, antikaon-nucleon scattering lengths, X-ray spectroscopy
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INTRODUCTION

This research program at the DAΦNE electron-positron collider of Laboratori Nazionali di Frascati is focussed on experimental studies of kaonic atoms, taking advantage of the low-energy kaons produced in the Φ-meson decay [1]. The low-energy kaon-nucleon interaction in kaonic hydrogen and kaonic deuterium can be investigated under unprecedented conditions.

Kaonic hydrogen atoms are the simplest atomic systems with strangeness in which the strong interaction kaon-proton results in the experimentally observable shift and width of the 1s atomic ground state. The low energy kaon-proton interaction was found to be repulsive in an experiment at KEK in agreement with the kaon-nucleon scattering data - thus solving the unclear situation about the sign of the interaction. The sub-threshold resonance Λ(1405) is responsible for the repulsive interaction at threshold [2] but can also lead to deeply bound kaonic nuclear clusters in which highly dense nuclear system are present [3]. Several experiments at KEK [4], GSI [5] and LNF [6] report positive results on kaonic nuclear clusters.

The low-energy antikaon-nucleon interaction is still an open field since precision data are missing and furthermore kaonic deuterium was never studied before. For the determination of the isospin-dependent scattering lengths however shift and width of kaonic hydrogen and kaonic deuterium are necessary.

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EXPERIMENTAL METHOD

In the DEAR experiment the kaons from Φ meson decay are degraded and stopped in a cryogenic gas target. X-rays are detected by an array of 16 CCDs, which provide excellent energy resolution as well as large solid angle and allow the selection of X-ray events by pattern analysis - but this kind of detectors has no timing capability. Extremely important was an elaborate shielding of the setup. We succeeded to suppress the low energy X-ray background by about 2 orders of magnitude.

DEAR RESULTS

Final results on Kaonic Hydrogen

After successfully measuring 3 kaonic nitrogen X-ray transitions for the first time [7] the kaonic hydrogen X-ray spectrum was measured. The up-to-now most accurate values for the strong interaction shift and width were extracted. The final DEAR results [8] $\varepsilon_{1s} = -193 \pm 37(stat.) \pm 6(syst.)$ eV and $\Gamma_{1s} = 249 \pm 111(stat.) \pm 30(syst.)$ eV show smaller values for the shift and width and smaller error bars compared to the KpX experiment [9] (see fig.1).

Comparison with recent Theory

A comparison with recent theoretical studies are given in fig. 1. In ref. [10] the hypothesis by Dalitz and Tuan [11] on the dominant role of the $\bar{K}^0 n$–cusp is reproduced. T1 is according to this approach taking the complex scattering length of ref. [12]. Using the $SU(3)$ chiral Lagrangians and relativistic coupled channels technique the experimental data on the cross sections for the elastic and inelastic $K^- p$ scattering were fitted and the energy level displacement of the ground state of kaonic hydrogen were predicted (T2). In refs. [12], [14], [15] a model for $\bar{K}N$ scattering at threshold was proposed and the energy level displacement of the ground state of kaonic hydrogen calculated (T3).

NEXT STEPS: SIDDHARTA AND THE EXPERIMENTAL PROGRAM

In order to overcome the limitations of the DEAR experiment in background suppression new X-ray detectors are in development within the SIDDHARTA project now. Large area silicon drift detectors (active area 1 cm^2) provide excellent energy resolution comparable with CCDS, but provide also timing capability. Using a triple coincidence with the charged kaon pair from Φ meson decay (SDD x K^+ x K^-) the background will be suppressed by about 2-3 orders of magnitude [16].
In the next step of the experiment strong interaction shift and width of kaonic deuterium will be measured for the first time. Together with a high precision measurement of the

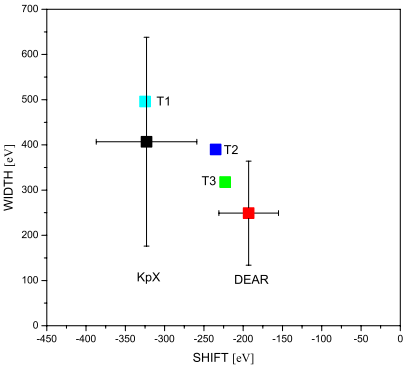

FIGURE 1. Results for the strong interaction shift and width of the KpX experiment and this experiment. Recent theoretical results T1, T2 and T3 are displayed. Details are given in the text.

kaonic hydrogen shift and width the extraction of the isospin separated scattering lengths will be performed. Further measurements include the measurement of the kaonic helium (K^3He, K^4He) X-ray spectrum.

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