Kaonic Atoms at DAΦNE: DEAR and SIDDHARTA

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Introduction

Precision measurements of X-ray transitions in hadronic atoms, like pionic hydrogen and kaonic hydrogen, are used to extract the meson-nucleon scattering lengths near zero energy. Whereas in the pionic hydrogen case high accuracy in the experimental observables (shift ϵ_{1s} and width Γ_{1s} of the ground state due to strong interaction) is already reached, the kaonic hydrogen case is still waiting for high precision measurements. Furthermore, no experimental studies on kaonic deuterium were performed up to now. Therefore, the goal of the SIDDHARTA project(silicon drift detector for hadronic atom research by timing application)- which is the natural continuation of the DEAR project [1] - are precision measurements at the percent level of ϵ_{1s} and Γ_{1s} in kaonic hydrogen as well as in kaonic deuterium. From these quantities the desired isospin dependent scattering lengths can be determined. In the light of experimental findings of deeply bound kaonic systems at KEK [2] and at FINUDA/LNF [3] the information about the $\Lambda(1405)$ sub-threshold resonance is important. This resonance is responsible for the repulsive character of the kaon-proton interaction [4] and is considered as doorway for the formation of kaonic nuclear clusters [5] .
The DAΦNE electron-positron collider at Laboratori Nazionali di Frascati (LNF)

provides a unique source of negative kaons from Φ meson decay. With a branching ratio of ~50 percent nearly mono-energetic charged kaons are emitted back-to-back [6]. For the further stage of the experiment the correlation between the kaon pair and the X-ray will be used to efficiently suppress the background events. The combination of the unique features of DAΦNE and the new detector system will open the way to study the low-energy kaon-nucleon interaction at utmost precision.

Kaonic hydrogen

The principle of the DEAR experimental method to detect kaonic X-rays is straight forward. Kaonic atoms are produced by stopping negative charged kaons in a cryogenic gas target. The kaonic atoms are formed in high n states. The subsequent electromagnetic cascade itself is a non-trivial interplay of different processes - radiative X-ray transitions predominantly take place in the last steps.
The cryogenic gas target provides high density and therefore high kaon stopping efficiency and furthermor high yields of kaonic X-rays. This target volume is surrounded by an array of X-ray detectors characterized by high energy resolution and high X-ray efficiency. The DEAR experiment uses CCDs which fulfill these demands but background suppression is only possible by discriminating pixel clusters (clusters of more than 2 hit pixels) which are due to charged particles or high energetic γ rays. The DEAR collaboration showed the functionality of the setup by measuring X-rays from kaonic nitrogen and succeeded in measuring X-rays from 3 kaonic nitrogen transitions for the first time [7]. After this proof of the experimental method, we measured the X rays emitted from kaonic hydrogen by using a cryogenic hydrogen target (density 3 percent of liquid density). Due to high X-ray background the cateful study of the background data was important, see [8]. The analysis yielded the following values for the strong interaction shift and width :

$$\epsilon_{1s} = -193 \pm 37(stat.) \pm 6(syst.)eV \tag{1}$$

$$\gamma_{1s} = 249 \pm 111(stat.) \pm 30(syst.)eV \tag{2}$$

Our results verify the repulsive character of the interaction kaon-proton found in the KpX experiment at KEK [9] but we get smaller values and also smaller error bars.

These most precise results obtained up to now raised considerable interest and triggered new theoretical studies [10, 11, 12, 13, 14]. By using a relativistic field theoretical model [10] the DEAR data can be reproduced. On the other hand the careful analysis of scattering data and the DEAR data [12] finds ϵ_{1s} compatible with the DEAR result but finds larger values for the width.

SDDs and New Setup

In order to suppress the X-ray background efficiently new X-ray detectors SDDs providing timing capabilities are in development now. Large area SDD detectors (1 cm^2) exhibit high efficiency and energy resolution comparable with that of CCDs

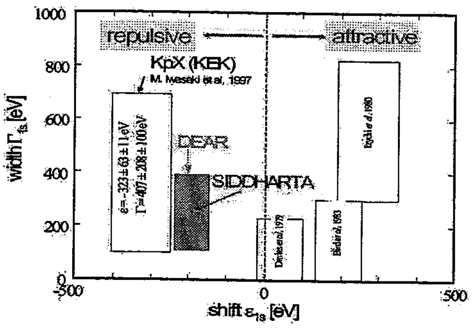

Figure 1: Comparison of the DEAR result with former experimental results obtained by X-ray spectroscopy of kaonic hydrogen. Indicated is also the precision goal of SIDDHARTA.

(~150 eV@6 keV). An array of ~200 SDDs will surrounding the target gas volume. By applying a triple coincidence (see fig. 2, left) we expect a background suppression by ~3 orders of magnitude, thus giving a signal to background ration of 10:1 for kaonic hydrogen and about 1:1 for kaonic deuterium (assuming a K_α yield of ~0.2). A new dedicated target-detector system is in development now. Monte Carlo studies of the X-ray spectrum of kaonic deuterium showing the kaonic deuterium X-ray spectrum (fig.2, right). For a measuring time of about 30 days about 3000 K_α events can be recorded thus opening the way to high precision measurements.

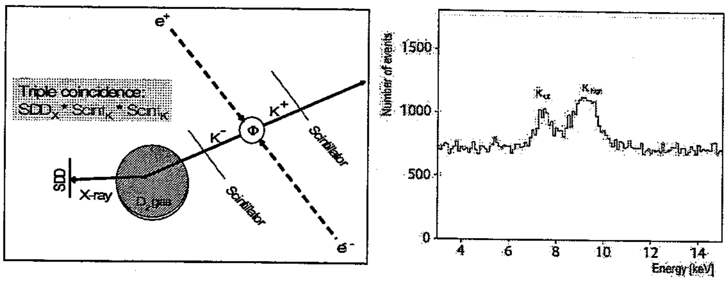

Figure 2: Scheme of triple coicidence to be applied in SIDDHARTA (left). Monte-Carlo simulation of kaonic deuterium K-lines (right) with a K_α yield of 0.2 percent.

Summary and Outlook

DEAR was one of the first experiments at DAΦNE showing the successful production X-ray spectroscopy of kaonic atoms. After the study of kaonic nitrogen X-ray a measurement of the kaonic hydrogen spectrum was successfully performed yielding the most precise values for ϵ_{1s} and Γ_{1s}. Large area SDDs and a newly designed setup are in development now. A new precision experiment on kaonic hydrogen and the first ever on kaonic deuterium are envisaged in the framework of the SIDDHARTA project. Furthermore, within SIDDHARTA measurements on kaonic helium isotopes and a feasibilty study of sigmaonic atoms are planned.

Acknowledgements

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