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Citation: AIP Conference Proceedings **1735**, 080014 (2016);
View online: https://doi.org/10.1063/1.4949467
View Table of Contents: http://aip.scitation.org/toc/apc/1735/1
Published by the American Institute of Physics

SIDDHARTA Results and Implications of the Results on Antikaon-Nucleon Interaction

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Abstract. The interaction of antikaons (K^-) with nucleons and nuclei in the low-energy regime represents an active research field in hadron physics. There are important open questions like the existence of antikaon nuclear bound states like the prototype system being K^-pp. Unique and rather direct experimental access to the antikaon-nucleon scattering lengths is provided by precision X-ray spectroscopy of transitions in low-lying states in light kaonic atoms like kaonic hydrogen and helium isotopes. In the SIDDHARTA experiment at the electron-positron collider DAΦNE of LNF-INFN we measured the most precise values of the strong interaction observables, i.e. the strong interaction on the 1s ground state of the electromagnetically bound K^-p atom leading to energy shift and broadening of the 1s state. The SIDDHARTA result triggered new theoretical work, which achieved major progress in the understanding of the low-energy strong interaction with strangeness reflected by the antikaon-nucleon scattering lengths calculated with the K^--proton amplitudes constrained by the SIDDHARTA data. The most important open question is the experimental determination of the hadronic energy shift and width of kaonic deuterium which is planned by the SIDDHARTA-2 Collaboration.

INTRODUCTION

For decades the interaction of antikaons (K^-) with nucleons and nuclei in the low-energy regime has been the subject of studies in experiment and theory (for reviews see [1]). A special role in the $\overline{K}N$ interaction is played by the sub-threshold resonance $\Lambda(1405)$. It influences strongly the hadronic mass shift and width at threshold. On the other hand it is still a question of debate whether the $\Lambda(1405)$ is a one pole resonance or has a more complicated structure [2]. The elementary case of the antikaon interaction with the nucleons was puzzling because of contradictory results

XVIth International Conference on Hadron Spectroscopy
AIP Conf. Proc. 1735, 080014-1–080014-5; doi: 10.1063/1.4949467
Published by AIP Publishing. 978-0-7354-1389-4/$30.00

from experiments. Now much improved experimental techniques like X-ray detection systems for the precise studies are available. The interaction of K$^-$ ($\overline{K}$) with nucleons in the two isospin states can be precisely determined by X-ray spectroscopy of the simplest kaonic atoms, i.e. kaonic hydrogen and kaonic deuterium. In these exotic atoms the strong interaction leads to an energy shift ϵ_{1s} from the calculated electromagnetic value (i.e. without strong interaction) and a broadened width Γ_{1s} of the 1s ground state. By measuring the X-ray transitions to the 1 s state ϵ_{1s} and Γ_{1s} can be determined. Recently advances in the theoretical description of the $\overline{K}N$ interaction on the basis of field theory were made. The measured hadronic shift and width of kaonic hydrogen are used as anchor points for these calculations. In order to determine the isospin-separated scattering length for the isospin I=0 scattering length a$_0$ scattering length and the I=1 scattering length a$_1$ respectively.

KAONIC ATOMS

The lightest kaonic atom is the K$^-$p atom in which the principal interaction is the electromagnetic interaction accompanied by the strong interaction of the kaon with the proton which is measurable by X-ray spectroscopy of the radiative transitions from the np states (2p, 3p, ...) to the 1s ground state (K transitions). The energy shift ϵ_{1s} is calculated by Equation1, ϵ_{1s} is given by the difference between the measured $E^{meas.}_{np\to 1s}$ and the calculated transition energy $E^{em}_{np\to 1s}$.

$$\epsilon_{1s} = E^{meas.}_{np\to 1s} - E^{em}_{np\to 1s} \tag{1}$$

Using Equation2 [3] the K$^-$-p scattering length a$_p$ can be calculated.

$$\epsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu_c^2 a_p(1 - 2\alpha\mu_c(ln\alpha - 1)a_p) \tag{2}$$

The scattering length a$_p$ is related to the isospin-dependent scattering lengths by Equation3

$$a_p = \frac{1}{2}(a_0 + a_1). \tag{3}$$

In the past different experiments on the X-ray spectrum of kaonic hydrogen were performed - before SIDDHARTA even the most recent ones [4, 5] were leaving open the question about the quantitative value of the hadronic broadening. The experimental studies on kaonic atoms at DAΦNE are focused on the X-ray spectroscopy of kaonic hydrogen and helium isotopes taking advantage of the ideal conditions of this Φ-factory. The SIDDHARTA experiment used silicon drift detectors (SDDs) for X-ray spectroscopy of kaonic atoms for the first time. The timing capability of SDDs provided the use of a triple coincidence of X-ray and the back-to back emitted kaons from the Φ meson decay. in Figure 1 a sketch of the SIDDHARTA setup is displayed.

As a first step SIDDARTA succeeded in break-throughs like the first measurement of the strong interaction in kaonic helium-3 [6] and the first measurement of kaonic helium-4 with a gas target [7]. A highlight of SIDDHARTA was the measurement of the kaonic hydrogen X-ray spectra and the extraction of ϵ_{1s} and Γ_{1s} with unprecedented accuracy [8].

$$\varepsilon_{1s} = -283 \pm 36(stat) \pm 6(syst)eV \tag{4}$$

$$\Gamma_{1s} = 541 \pm 89(stat) \pm 22(syst)ev \tag{5}$$

The necessary input to disentangle a$_0$ and a$_1$ will be provided by the determination of the shift sand width of kaonic deuterium. This is a far more challenging experimental issue. The kaonic deuterium case is still open and will be studied by SIDDHARTA-2 applying a significantly improved setup.

Kaonic Deuterium

Experimentally the case of kaonic deuterium is still open and challenging due to the anticipated low X-ray yield (~ 10 % of the kaonic hydrogen yield) which demands highly efficient X-ray detection and the expected larger hadronic width [9, 10, 11, 12, 13] which requests largely improved background suppression. For the Monte Carlo simulation of the kaonic deuterium X-ray spectrum a value of 800 eV for shift and width were used according to theory.

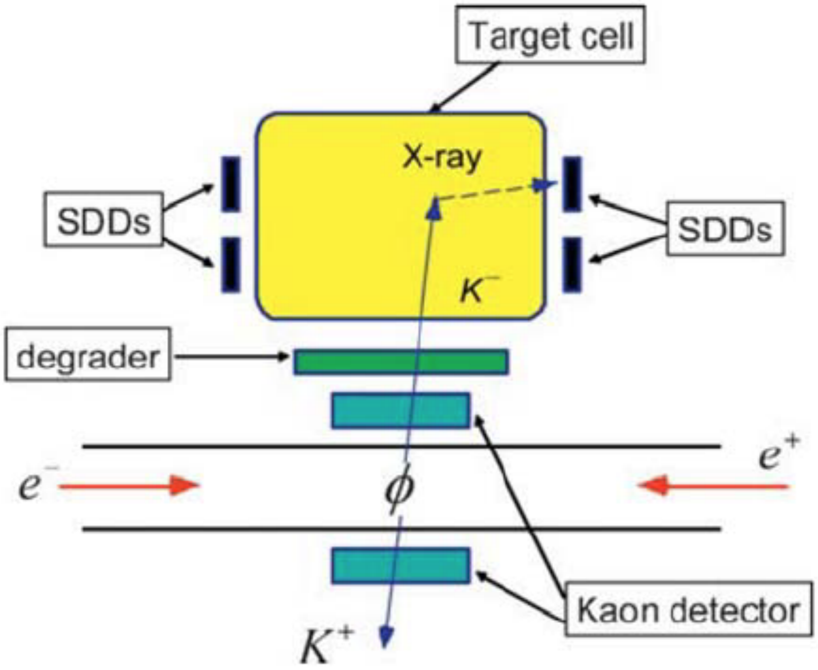

FIGURE 1. Sketch of the SIDDHARTA setup. A triple coincidence of the two emitted charged kaons from the Φ meson decay and the X-ray allows an efficient suppression of uncorrelated background events.

Nevertheless SIDDHARTA performed an exploratory X-ray study with a pure deuterium filling. An upper limit for the X-ray yield of the K lines could be extracted from the data: total yield <0.0143, Kα yield <0.0039 [14]. However, ϵ_{1s} and Γ_{1s} could not be determined due to the limited statistics and the background condition.

A new experiment SIDDHARTA-2 is planned which is based on a strongly improved apparatus. The improvements include an optimized geometry, deuterium gas density, discrimination of K^+, active shielding and better SDD timing performance by cooling. According to Monte Carlo studies one expects an X-ray energy spectrum shown in Fig. 2. This experiment is planned for DAΦNE, or as an alternative option at J-PARC.

SUMMARY AND OUTLOOK

The SIDDHARTA experiment at the electron-positron collider DAΦNE measured the strong interaction $\overline{K}p$ at threshold with unprecedented accuracy. Important implications for the theory of the strong interaction with strangeness in the low-energy regime were provided by the SIDDHARTA constraints. Based on a field theoretical coupled channel approach [16] a consistent picture was obtained. The antikaon-nucleon interactions Lambda(1405) and the question of bound systems like the $\overline{K}NN$ system are objects of recent research [17]. Also still open is the challenging case of kaonic deuterium which will be attacked by the follow-up experiment SIDDHARTA2 which is aiming at the determination of the hadronic shift and width to enable the extraction of the isospin-separated scattering lengths a_0 and a_1.

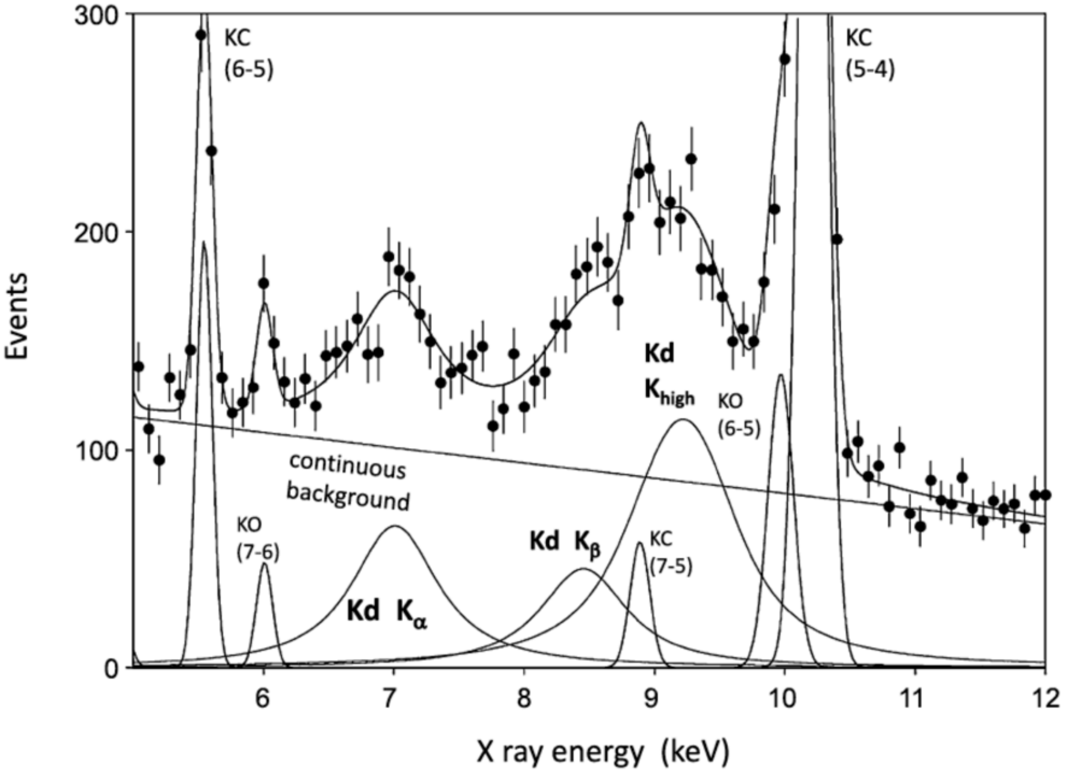

FIGURE 2. Monte-Carlo calculated X-ray spectrum of kaonic deuterium assuming ϵ_{1s} = -805 eV and Γ_{1s} = 750 eV [15]. The K transitions to the 1s ground state are indicated. With this values one gets an estimated precision of 70 eV in the shift and 150 eV in the width.

ACKNOWLEDGMENTS

We thank C. Capoccia, G. Corradi, B. Dulach, and D. Tagnani from LNF-INFN; and H. Schneider, L. Stohwasser, and D. Stückler from Stefan-Meyer-Institut, for their fundamental contribution in designing and building the SIDDHARTA setup. We thank as well the DAΦNE staff for the excellent working conditions and permanent support. Part of this work was supported by the European Community- Research Infrastructure Integrating Activity Study of Strongly Interacting Matter" (HadronPhysics2, Grant Agreement No. 227431, and HadronPhysics3 (HP3) Contract No. 283286) under the Seventh Framework Programme of EU; HadronPhysics I3 FP6 European Community program, Contract No. RII3-CT-2004- 506078; Austrian Science Fund (FWF) (P24756-N20); Austrian Federal Ministry of Science and Research BMBWK 650962/0001 VI/2/2009; Croatian Science Foundation under Project No. 1680; Romanian National Authority for Scientific Research, Contract No. 2-CeX 06-11-11/2006; and the Grant-in-Aid for Specially Promoted Research (20002003), MEXT, Japan.

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