Progress and perspectives in the low-energy kaon-nucleon/nuclei interaction studies at the DAΦNE collider

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Progress and perspectives in the low-energy kaon-nucleon/nuclei interaction studies at the DAΦNE collider

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(SIDDHARTA, SIDDHARTA-2 and AMADEUS collaborations)

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Abstract. Low-energy QCD is still lacking experimental results, fundamental for reaching a good understanding of the strangeness sector. The information provided by the low energy kaon-nucleon/nuclei interaction is accessible through the study of kaonic atoms and kaonic nuclear processes. The lightest atomic systems, namely the kaonic hydrogen and the kaonic deuterium, provide the isospin dependent kaon-nucleon scattering lengths by measuring the X-rays emitted during their de-excitation to the 1s level. The most precise kaonic hydrogen measurement to date, together with an exploratory measurement of kaonic deuterium and of upper-level transitions in kaonic helium 3 and kaonic helium 4 were carried out at the DAΦNE collider by the SIDDHARTA collaboration. Presently, a significantly upgraded setup developped by the SIDDHARTA-2 collaboration is ready to perform a precise measurement of kaonic deuterium and, afterwards, of heavier exotic atoms. In parallel, the kaon-nuclei interaction at momenta below 130 MeV/c is studied by the AMADEUS collaboration, using the KLOE detector and a dedicated setup inserted in the central region, near the interaction point. Preliminary results of the study of charged antikaons interacting with nuclei are shown, including an analysis of the controversial $\Lambda(1405)$.

1. Introduction

Reliable information on $\bar{K}N$ interaction at threshold was provided only in the 1990s by measuring the strong-interaction energy shift ϵ and width Γ of kaonic-hydrogen $1s$ state, at KEK-PS in Japan [1] and afterwards, at DAFNE in Italy [2]. From the two values, the K^-p scattering length was extracted, using a Deser-Trueman-like formula [3], lately improved to account for the isospin-breaking corrections [4]. The measurement allowed a consistent interpretation of the scattering data [5] and the calculation of chiral SU(3) meson-baryon effective Lagrangian. However, sub-threshold amplitudes were extrapolated with large uncertainties due to the experimental precision. Recently, the SIDDHARTA collaboration obtained more accurate values for both ϵ and Γ for kaonic hydrogen, thus providing stronger constraints on the theoretical models. The new data also motivated novel calculations regarding the structure of $\Lambda(1405)$ and theoretical investigations about the existence of kaonic nuclear clusters [6], both topics now under experimental study within the AMADEUS collaboration.

2. SIDDHARTA experiment

The SIDDHARTA experiment was performed at the upgraded DAΦNE e^+e^- collider in Frascati, Italy [7]. The beam energy is tuned to create ϕ mesons, which decay in K^+K^- pairs with a BR of 49.1%. The monochromatic, low-energy charged kaons are degraded, then stopped in a cryogenic gaseous target, producing kaonic atoms. The target is a critical item, the yields of kaonic atom X-rays decreasing sensitively with the gas density, due to Stark mixing. On the other hand, a low density does not permit efficient stopping and increases the kaons in-flight decay. For the SIDDHARTA optimized density, the yield was $\sim 1\%$ when filled with hydrogen and will presumably drop to $\sim 0.1\%$ for deuterium. The trigger was given by K^-K^+ coincident hits on fast scintillators. The kaonic atom X-rays were detected with 144 silicon drift X-ray detectors (SDDs), 1 cm^2 each, surrounding the target. The SDDs, developed by the collaboration, have an energy resolution of 180 eV FWHM at 6 keV, while their time response is below 800 ns FWHM. The trigger signal and the fast X-ray detectors confered a high background rejection, most of the background deriving from beam losses, uncorrelated with the Φ production.

2.1. SIDDHARTA results and ongoing upgrade

The data analysis used a global fit of both hydrogen and deuterium X-ray spectra to extract ϵ and Γ, thus improving the background subtraction. The fit lines are indicated in Fig. 1. The kaonic-hydrogen X-ray transitions were clearly observed, while kaonic deuterium ones were not. This agrees with the theoretical predictions, indicating one order of magnitude lower yield [8]. The repulsive-type shift observed is in agreement with the K^-p scattering data. Other characteristic X-rays, coming from the calibration foils and from the setup components, as well as Xrays from heavier kaonic-atoms produced in the target wall, were properly identified. The details of the analysis and the setup description are given in [9]. The fit results for the $1s$ strong-interaction shift and width in kaonic hydrogen are

$$\epsilon = -283 \pm 36(\text{stat}) \pm 6(\text{syst})\ \text{eV}$$

and

$$\Gamma = 541 \pm 89(\text{stat}) \pm 22(\text{syst})\ \text{eV},$$

respectively. The values are in agreement with the recent theoretical works [10], so yielding important constraints on the description of low-energy $\bar{K}N$ interactions [6]. Still, the full determination of the isospin-dependent $\bar{K}N$ scattering lengths requires a second measurement, namely the shift and the width of kaonic-deuterium $1s$ state. Therefore, the SIDDHARTA-2 experiment is being prepared to measure the -one order of magnitude lower yield- kaonic deuterium X-rays, by significantly improving the signal to background ratio [11]. The full results will grant an important progress of the theoretical interpretation.

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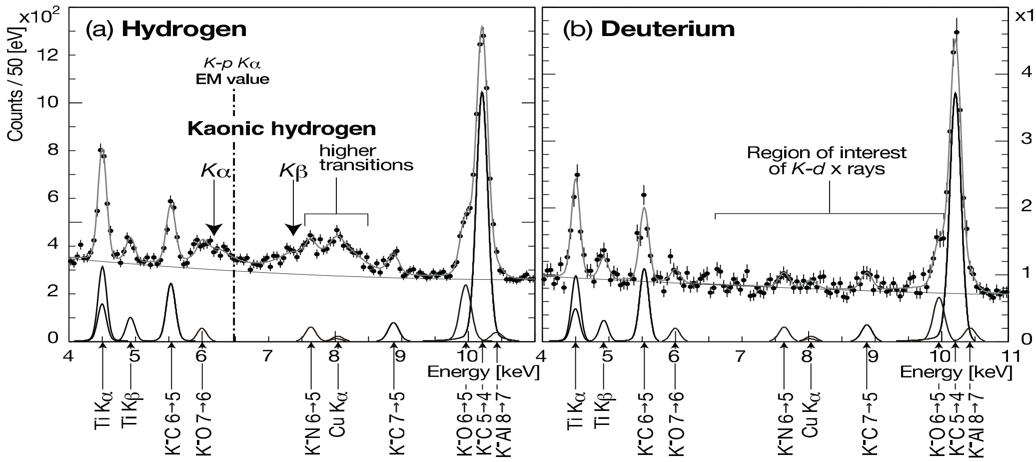

Figure 1. Global fit of the X-ray spectra from kaonic hydrogen (a) and kaonic deuterium (b). The dot-dashed vertical line indicates the EM energy of the kaonic-hydrogen Kα X-ray.

3. AMADEUS

A research line complementary to that of exotic atoms, the AMADEUS experiment at DAΦNE deals with the investigation of low-energy kaon-nucleon/nuclei hadronic interaction inside the nucleus. For that purpose, signals from K^- absorption at rest and in flight (with momenta below 127 MeV/c), are investigated using a sample of 1.4 fb^{-1} from the KLOE experiment data. In a first phase, components of the detector [12], like the gas filling the drift chamber (mainly ^{4}He) and the drift chamber wall (mainly ^{12}C), were used as active targets. The interpretation of the data will allow extracting qualitative and quantitative outputs for the search of kaonic nuclear clusters [13] and a new study of the debated $\Lambda(1405)$ resonance [6], to be added to the pp and heavy ion collisions data.

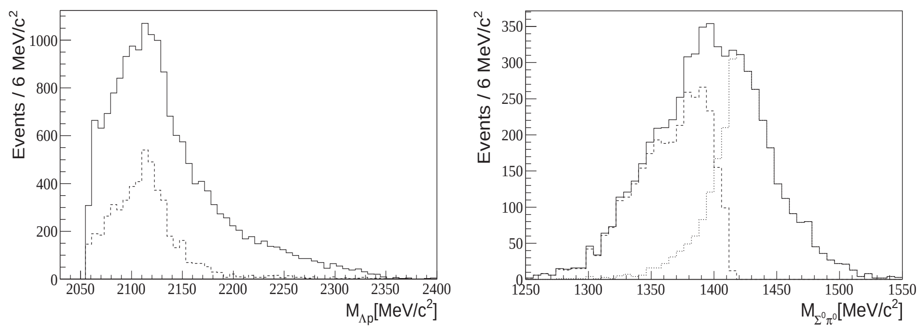

Figure 2. Left: Λp invariant mass for the inclusive Λp selection (continuous line) and for events with an extra π^- detected (dashed line). Right: $\Sigma^0\pi^0$ invariant mass (dashed and pointed lines represent the at-rest and in-flight components, respectively).

The invariant mass spectra for the Λp inclusive selection (expected decay channel of a K^-pp cluster) is shown in the left part of Fig. 2 for the ^{4}He events. The low invariant mass region is populated mainly by events coming from the single nucleon absorption (1NA) process, the proton in the final state coming from the participant nucleons trough the Σ/Λ nuclear conversion taking place inside the residual nucleus. The 1NA process is characterized by an additional negative pion in the final state. This subsample is represented by the dashed line in Fig. 2 (left), with arbitrary normalization, to be compared with the full spectrum. The ongoing analysis of Lambda-baryon channels will further provide the fraction of single/multi nucleon absorption, as well as the rates of nuclear Σ/Λ conversion for the given energy range.

For the study of the $\Lambda(1405)$, the $\Sigma^0\pi^0$ decay channel has been analyzed. The invariant mass distribution for events in ^{12}C, shown in the right part of Fig. 2, exhibits a significant fraction of events above the kinematical limit of the K^- absorption at rest (1416 MeV/c^2). A similar behaviour, explained by the small difference in the last nucleon's binding energies, was observed on ^{4}He. Consequently, the data set was split into in-flight and at rest candidate events. Further analysis indicates both distributions have a two-component structure; the lower momentum one correlated with high masses and vice versa. The ongoing work in extracting the resonant and non-resonant parts and the characterization of the line shapes of the resonance is important to correctly interpret the results and compare them to theoretical models.

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