A new measurement of kaonic hydrogen atom X-rays at DAΦNE

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Kaonic hydrogen atom provides a unique laboratory for studying the kaon-nucleon strong interaction at the threshold energy. The SIDDHARTA collaboration has measured the K-series x rays of kaonic hydrogen atoms at the DAΦNE electron-positron collider of Laboratori Nazionali di Frascati, and has determined the strong-interaction shift and width of the 1s atomic energy level with the best accuracy up to now. The measured shift and width result in the most precise value of the $\overline{K}N$ scattering lengths which will provide vital constraints on the theoretical description of the low-energy $\overline{K}N$ interaction.

1 Introduction

Kaonic hydrogen atom is a Coulomb bound system formed by a K^- and a proton, but is affected by the strong interaction at short range. The influence appears as a shifting of the 1s atomic energy level from its pure electromagnetic (EM) value and a broadening due to reducing the lifetime of the state by the absorption. The shift and width can be deduced

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by the spectroscopy of kaonic-hydrogen x-ray transitions feeding the 1s states, namely the K-series x rays.

It is well known that the measured strong-interaction shift and width are directly related to the real and imaginary parts of the complex $K^- p$ S-wave scattering length [1]. The kaonic-hydrogen x-ray data are therefore crucial for theories of the $\overline{K}N$ system together with the low-energy $\overline{K}N$ data.

The low-energy $\overline{K}N$ system has attracted attention as a testing ground for chiral SU(3) dynamics in low-energy QCD and the role of explicit chiral symmetry-breaking due to the relatively large strange quark mass. The data are also strongly related to recent hot topics – the structure of the $\Lambda(1405)$ resonance and the deeply bound kaonic systems. Recent progress of this field is summarized in [2].

In the current experiment, called SIDDHARTA, we have measured the K-series x rays of kaonic hydrogen atoms and determined the most precise values of the strong-interaction shift and width of the 1s energy level. Recently, the final result is submitted for publication [3]. In this paper, we present an overview of the kaonic hydrogen measurement.

2 Experiment

The SIDDHARTA experiment was performed at the DAΦNE positron-electron collider. The collider produces the ϕ-resonances of which 49 % decay into back-to-back K^+K^- pairs. Resulting monochromatic low-energy kaons were degraded and stopped in a cryogenic hydrogen gaseous target. A coincidence of two plastic scintillation counters mounted above and below the e^+e^- interaction point was used as a kaon trigger. X rays emitted from the kaonic atoms were detected by 144 silicon drift detectors (SDDs), each having an effective area of 1 cm^2, developed within a European research project devoted to this experiment. The SDD has an excellent energy resolution of $\sim$ 180 eV (FWHM) at 6 keV and a good timing resolution of $\sim$ 800 ns (FWHM). A detailed description of our experimental setup is given in [3,4].

3 Result

Figure 1 (a) shows a kaonic-hydrogen x-ray spectrum. We have also measured x-ray spectrum with a deuterium target (for the first-ever exploratory measurement of kaonic-deuterium x rays), as shown in Fig. 1 (b). The kaonic-hydrogen x-ray transitions were clearly observed while those for kaonic deuterium were not visible. This appears to be consistent with the theoretical expectation that kaonic deuterium x rays have one order lower yield per stopped K^- and greater width than those of kaonic hydrogen x rays (*e.g.*, [5]).

A dot-dashed line in Fig. 1 (a) indicates the EM value of the kaonic-hydrogen $K\alpha$. Comparing the kaonic-hydrogen $K\alpha$ peak and the EM value, there is no room for doubt about a

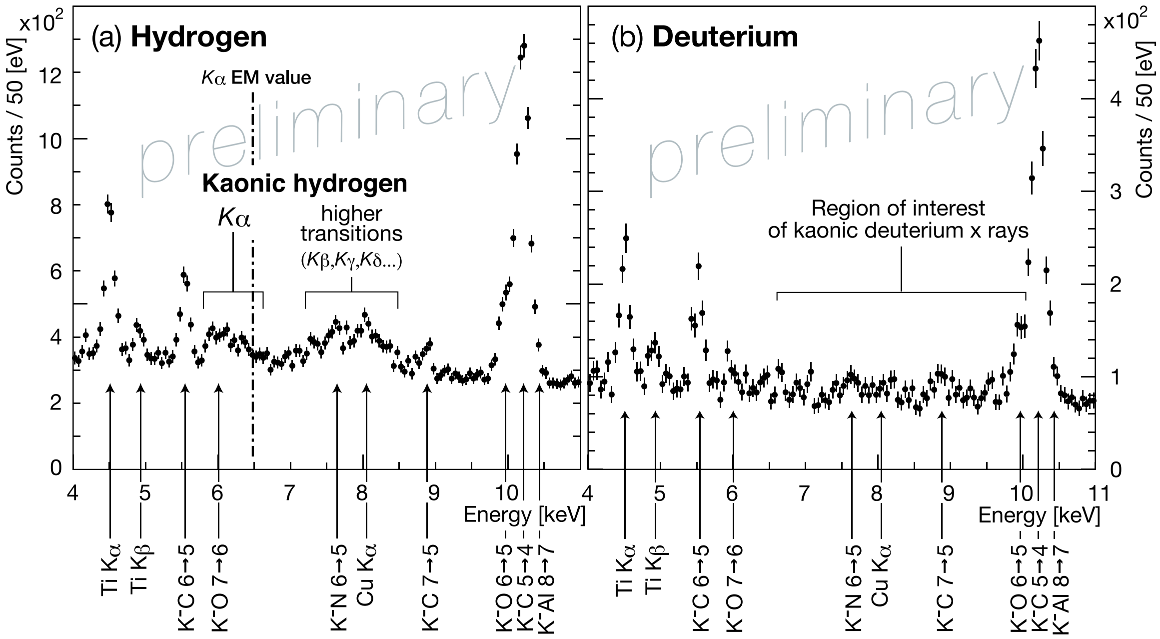

Figure 1: The measured x-ray spectra taken (a) with hydrogen target and (b) with deuterium target. The dot-dashed vertical line indicates the EM value of the kaonic-hydrogen $K\alpha$.

repulsive-type shift of the kaonic-hydrogen 1s-energy level, which is consistent with the analysis of the low energy $\overline{K}N$ scattering data.

The continuous background is related to the following two type of particles: the charged kaon secondaries (synchronous background) and lost beam particles (asynchronous background). In the most recent measurement of the kaonic hydrogen x-ray (DEAR) [6] performed at DAΦNE as well, the kaonic-hydrogen spectrum suffered from the huge asynchronous background due to lack of the timing capability of x-ray detectors (CCDs) used. The event selection using time difference between kaon arrival (with kaon detectors) and x-ray detection (with SDDs) significantly reduced the asynchronous background and improved the signal-to-background ratio by more than a factor of 10 with respect to the corresponding DEAR ratio of about 1/100.

Many other kaonic-atom x rays and characteristic x rays were detected in both spectra as indicated with arrows in the figures. Those kaonic-atom lines are attributable to the target-cell wall made of Kapton polyimide film ($C_{22}H_{10}O_5N_2$) and its support frames made of aluminum. The characteristic x rays come from high-purity titanium and copper foils installed for *in-situ* x-ray energy calibration.

There are three background x-ray lines overlapping with the kaonic-hydrogen signals : kaonic oxygen 7-6 (6.0 keV), kaonic nitrogen 6-5 (7.6 keV) and fluorescence x ray of copper

$K\alpha$ (8.0 keV). In the fitting procedure of the kaonic-hydrogen spectrum, it turned out to be essential to use the kaonic-deuterium spectrum to quantify the kaonic background x-ray lines. We have therefore performed a global simultaneous fit of the hydrogen and deuterium spectra, where the background intensities were determined using both spectra and a normalization factor defined by the ratio of the high-statistics kaonic-carbon 5-4 peak in both spectra.

As a result, we have determined the most precise values of the strong-interaction energy-level shift and width of the kaonic-hydrogen atom $1s$ state [3]. Our determination of the shift and width allows more precise evaluation of $\overline{K}N$ scattering lengths which will yield vital constraints on the theoretical description of the low-energy $\overline{K}N$ interaction.

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References

[1] S. Deser et al., Phys. Rev. 96 (1954) 774; T. L. Trueman, Nucl. Phys. 26 (1961) 57; A. Deloff, Phys. Rev. C 13 (1976) 730.

[2] C. Curceanu, J. Zmeskal, Mini-Proceedings of ECT Workshop "Strangeness in Nuclei", arXiv:1104.1926, and references therein.

[3] SIDDHARTA Collaboration, arXiv:1105.3090, Phys. Lett. B, submitted for publication.

[4] SIDDHARTA Collaboration, Phys. Lett. B 681 (2009) 310; Phys. Lett. B 693 (2011) 199.

[5] T. Koike, T. Harada, Y. Akaishi, Phys. Rev. C 53 (1996) 79.

[6] G. Beer *et al.*, Phys. Rev. Lett. 94 (2005) 212302.