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Kaonic ^{3}He and ^{4}He measurements in the SIDDHARTA experiment at the DAΦNE collider

H. Tatsuno[1,a], M. Bazzi[1], G. Beer[2], L. Bombelli[3], A.M. Bragadireanu[1,4], M. Cargnelli[5], C. Curceanu (Petrascu)[1], A. d'Uffizi[1], C. Fiorini[3], T. Frizzi[3], F. Ghio[6], C. Guaraldo[1], R.S. Hayano[7], M. Iliescu[1,4], T. Ishiwatari[5], M. Iwasaki[8], P. Kienle[5,9], P. Levi Sandri[1], A. Longoni[3], J. Marton[5], S. Okada[8], D. Pietreanu[1,4], T. Ponta[4], A. Rizzo[1], A. Romero Vidal[10], E. Sbardella[1], A. Scordo[1], H. Shi[7], D.L. Sirghi[1,4], F. Sirghi[1,4], A. Tudorache[4], V. Tudorache[4], O. Vazquez Doce[9], E. Widmann[5], B. Wünschek[5], and J. Zmeskal[5]

[1] INFN, Laboratori Nazionali di Frascati, Frascati (Roma), Italy
[2] Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
[3] Politecnico di Milano, Sezione di Elettronica, Milano, Italy
[4] Horia Hulubei National Institute of Physics and Nuclear Engineering, Magurele, Romania
[5] Stefan-Meyer-Institut für subatomare Physik, Vienna, Austria
[6] INFN Sezione di Roma I and Istituto Superiore di Sanità, Roma, Italy
[7] The University of Tokyo, Tokyo, Japan
[8] RIKEN, The Institute of Physics and Chemical Research, Saitama, Japan
[9] Technische Universität München, Physik Department, Garching, Germany
[10] University of Santiago de Compostela, Santiago de Compostela, Spain

Abstract. The SIDDHARTA collaboration measured kaonic ^{3}He and ^{4}He $3d \rightarrow 2p$ X-rays with gaseous targets at the DAΦNE e^+e^- collider. The $2p$-state strong-interaction shifts and widths were precisely determined by using 144 high-resolution silicon drift detectors. The shift of $K^-{}^4$He is in good agreement with theoretical calculations and consistent with the recent experimental result of KEK-PS E570. The shift of $K^-{}^3$He is also determined for the first time. The newly determined widths are in agreement with optical model calculations.

1 Introduction

Kaonic atoms provide a unique possibility to determine the strong interactions of K^- with nucleon and nuclei at the low-energy limit. K^- atom is usually created by stopping a K^- beam in a target. The stopped K^- is captured with Coulomb force in highly excited states, for example, the principle number is about 30 for $K^-{}^4$He, and then cascades down with emitting radiative transition X-rays. At the end of the cascade, the K^- is absorbed by the nucleus through strong interaction. The atomic state before the absorption, so called the last atomic orbit, is shifted and broadened by the strong interaction. Therefore the effect is determined by measuring the transition X-rays to the last orbit.

The SIDDHARTA experiment measured four different targets, hydrogen, deuterium, ^{3}He, and ^{4}He. The measurements of K^-p and K^-d X-rays are motivated to determine the scattering length of K^- and nucleons which are the most fundamental and important parameters to understand the strong interaction at threshold. The details of these measurements are given in another contribution [1]. Here, we focus on the kaonic ^{3,4}He.

A puzzling situation remained for two decades in the $K^-{}^4$He $2p$-state shift. There was a 5σ discrepancy between theory and experiment. Theoretical calculations have shown basically no shift [2–4], on

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[a] e-mail: `hideyuki.tatsuno@lnf.infn.it`

the other hand past three experiments have shown about 40-eV repulsive shift [5–7] (repulsive means upward shift of the atomic level). This discrepancy has been solved in the recent measurements in KEK E570 [8] with liquid ^{4}He target and in SIDDHARTA [9] with gaseous target. Followed the ^{4}He measurement, SIDDHARTA also reported the shift of ^{3}He for the first time in the world [10].

Recently the nuclear potentials of $K^{-3,4}$He system have attracted attentions to search antikaon-nuclear clusters [11–14]. Theoretically, phenomenological optical-potential models [2,3] and a chiral unitary model [4] show no shifts and small widths (< 5 eV) for $K^{-3,4}$He $2p$ states. In addition, possible large shift and width (> 5 eV) have been predicted by a theory which accommodates deeply-bound $\bar{K}$-nuclear states [15]. However, no clear $K^{-3,4}$He potential is experimentally derived due to the lack of reasonable data for the strong interaction widths. SIDDHARTA has reported new experimental results of $K^{-3,4}$He $2p$-state width [16].

2 Experiment

The SIDDHARTA experiment was performed at the recently upgraded DAΦNE electron-positron collider in Frascati, Italy [17]. The beam energy of DAΦNE is tuned to create ϕ mesons, and the ϕ meson decays to K^+K^- pairs with about 49% of branching ratio. The monochromatic low-energy charged kaons can be easily degraded and stopped in a cryogenic gaseous target and kaonic atoms are efficiently produced. The gas-target system is a critical feature of the experiment, because the yields of kaonic atom X-rays decrease sensitively towards to higher density due to collisions with other atoms.

A 'charged-kaon trigger' is created with a coincidence of two plastic scintillation counters mounted top and bottom of the interaction point of e^+e^-. Kaonic atom X-rays were detected with 144 silicon drift X-ray detectors (SDDs) mounted surrounding the target. The SDDs, developed within a European research project devoted to this experiment, have a good energy resolution of about 180 eV FWHM at 6 keV and a timing resolution of about 800 ns (FWHM). A detailed description of the experimental setup and analysis is given in [9,10].

3 Results and Discussions

Figure. 1 shows a summary plot of the recent measurements of strong interaction shift of $K^{-3,4}$He $2p$ state. Filled circles show ^{4}He, and open circle shows ^{3}He. Negative sign means repulsive shift. The error bar is calculated as quadratic sum of statistical and systematic errors. The SIDDHARTA results of ^{4}He are consistent with the E570 one [8]. This means the small shift is confirmed with gaseous target. The shift of ^{3}He was firstly determined to be also small, 2±2(stat.)±4(syst.) eV. No large shift is established for kaonic helium $2p$ state.

The SIDDHARTA data were carefully analyzed and the strong interaction widths of kaonic helium were determined. Fig. 2 shows the correlation plot of shift and width of the SIDDHARTA results [16]. Filled circle shows ^{4}He, and open circle shows ^{3}He. The error bar is calculated as quadratic sum of statistical and systematic errors. For comparison, as an example, theoretical calculations of phenomenological optical potential model by Friedman [3] are also plotted. Filled square is ^{4}He and open square is ^{3}He. The result of ^{3}He is in good agreement with Friedman's calculation. The result of ^{4}He is in agreement within 2σ errors.

From the point of view of the optical potential model, the width should be small (< 5 eV) [3]. The SIDDHARTA results are not precise enough to conclude that, indeed, widths are smaller than 5 eV. If a large width (> 5 eV) is determined in a future high-precision measurement, other exotic explanation is essentially needed, such as deeply-bound antikaon-nuclear clusters [15]. In the future, SIDDHARTA-2, a major upgrade of SIDDHARTA, plans to perform more precise measurements and determine with eV precision both the shifts and the widths of kaonic ^{3}He and ^{4}He.

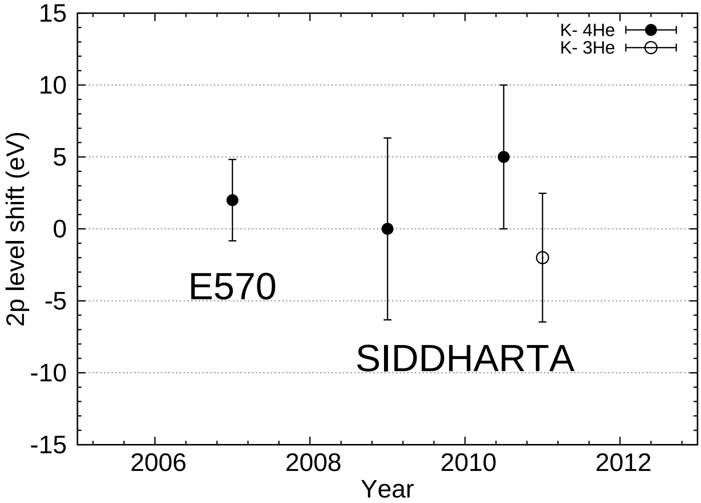

Fig. 1. Recent results of $K^{-3,4}$He $2p$-state strong interaction shift. Filled circle is ^{4}He, and open circle is ^{3}He. Negative sign means repulsive shift. The error bar is calculated as quadratic sum of statistical and systematic errors. The E570 result (liquid target) is taken from Ref. [8], and the SIDDHARTA results (gaseous targets) are taken from Refs. [9, 10]

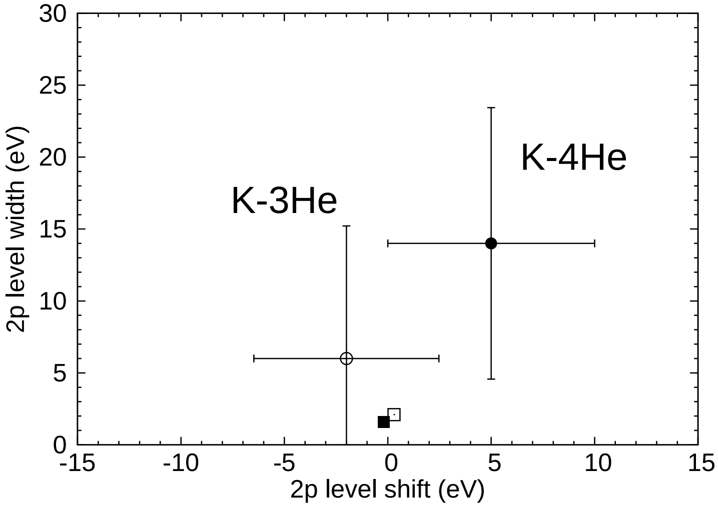

Fig. 2. Correlation plot of $K^{-3,4}$He $2p$-state strong interaction shift and width taken from Ref. [16]. Filled circle is ^{4}He, and open circle is ^{3}He. The error bar is calculated as quadratic sum of statistical and systematic errors. For comparison, theoretical calculations by Friedman [3] are also plotted: filled square is ^{4}He and open square is ^{3}He.

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