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Kaonic helium-4 X-ray measurement in SIDDHARTA

SIDDHARTA Collaboration

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ABSTRACT

The kaonic helium-4 $3d \to 2p$ X-ray transition was measured in a gaseous target, where Compton scattering in helium is negligible. The X-rays were detected with large-area Silicon Drift Detectors (SDDs) using the timing information of the K^+K^- pairs produced by ϕ decays at the DAΦNE e^+e^- collider. A new value of the strong interaction shift of the kaonic ^{4}He $2p$ state was determined to be 0 ± 6 (stat) ± 2 (syst) eV, which confirms the recently obtained result by the KEK-PS E570 group.

1. Introduction

Studies of kaonic atoms have provided important information on the K^--nucleus strong interaction in the low energy regime. Low-lying energy levels of kaonic atoms are shifted and broadened due to the strong interaction between the kaon and nucleus. The shifts and widths of kaonic atom X-rays have been measured using targets with atomic numbers from $Z = 1$ to $Z = 92$, and they are systematically well understood with optical models for $Z \geqslant 3$. These results have been used for calculations of the $\bar{K}N$ interaction [1–4].

However, until recently, there has been a discrepancy in the energy shift of kaonic helium. Three measurements of the energy shift of the kaonic ^{4}He $2p$ state made in the 70's and 80's [5–7] gave consistent results with an average value of the shift[1]

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[1] In this article, the shift ΔE is defined as $\Delta E = E_{\mathrm{exp}} - E_{\mathrm{e.m.}}$, where E_{exp} is an X-ray energy determined by experiment, and $E_{\mathrm{e.m.}}$ is a calculated energy with the QED effect only.

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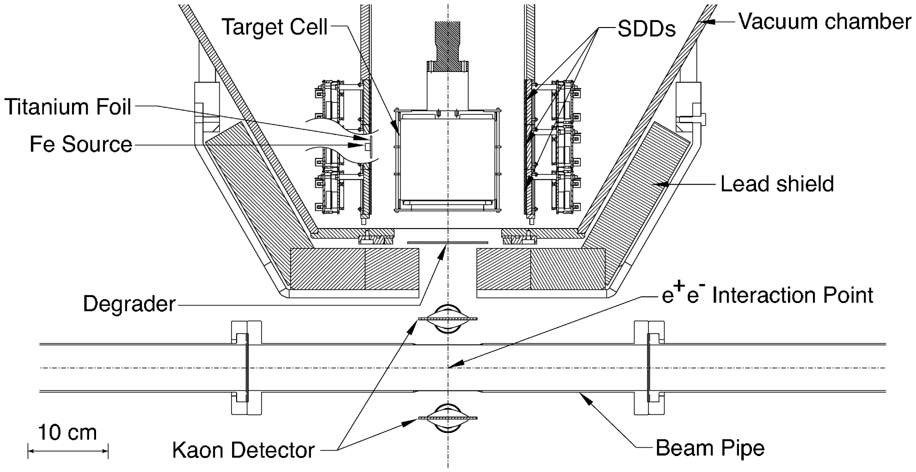

Fig. 1. An overview of the experimental setup. The whole system was installed at the interaction point of DAΦNE.

$\Delta E = -43 \pm 8$ eV [1,7]. On the other hand, the theoretical calculations based on the kaonic atom data with $Z \geqslant 3$ gave a shift of $\Delta E \sim 0$ eV (-0.13 ± 0.02 eV [1], -0.14 ± 0.02 eV [1], -0.4 eV [8], -1.5 eV [9]). Recent theoretical calculations predict a possible maximum shift of 10 eV [9]. No theoretical model could explain the large shift, and this difference between experiment and theory was known as the "kaonic helium puzzle".

A recent experiment performed by the KEK-PS E570 group gave a shift of $\Delta E = +2 \pm 2$ (stat) $\pm$ 2 (syst) eV [10], which is consistent with theory. This result has a much smaller error than the average value of the previous experimental results, but differs by more than three standard deviations, thus making an independent experimental verification necessary.

Here, we report a new measurement of the kaonic ^{4}He $3d \to 2p$ X-ray transition energy from which the strong interaction shift of the $2p$ level was determined. This measurement was made as part of the performance test of the SIDDHARTA setup at the DAΦNE ϕ factory of LNF in Frascati, Italy. The apparatus consists of an array of large-area Silicon Drift Detectors (SDDs) coupled to a gas target which is to be used for precision kaonic X-ray spectroscopy to determine the antikaon–nucleon isospin dependent scattering lengths.

An advantage of this new kaonic ^{4}He measurement comes from the use of a gas target resulting in negligible Compton scattering in helium — one of the sources of systematic errors in the previous experiments. The availability of kaons with low energy and low momentum spread produced by ϕ decays in the DAΦNE collider results in efficient kaon stopping in this gas target.

2. The SIDDHARTA experimental setup

The SIDDHARTA setup consists of three parts: a kaon detector, an X-ray detection system, and a cryogenic target system. Fig. 1 shows an overview of the setup. This whole system was installed at the e^+e^- interaction point of the DAΦNE collider.

The target cell is cylindrical with a radius of 6 cm and a height of 12 cm. It was filled with helium gas at a temperature of 27 K and a pressure of 0.95 bar, which corresponds to about 10.0 bar at normal temperature and pressure. The bottom of the vacuum chamber, shown in Fig. 1, has a circular window made of a Kapton foil with a radius of 6.5 cm, through which kaons enter the target cell. An energy degrader, installed on the bottom of the vacuum chamber, was adjusted in thickness to optimize the maximum number of kaonic helium X-rays. It had a step-like shape to compensate the ϕ boost effect caused by a finite crossing angle of the electron and positron beams.

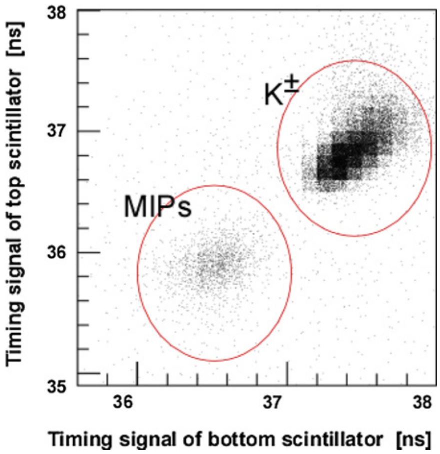

Fig. 2. Timing spectrum of the two scintillators in the kaon detector. The time difference between the clock signals delivered by DAΦNE and the coincidence of the two scintillators is shown. The K^+K^- and MIPs coincidence events are marked in the figure.

The K^+K^- pairs produced by ϕ decay were detected by a kaon detector, using a method similar to that used in a previous kaonic atom X-ray measurement at DAΦNE [11]. This detector consists of two scintillators installed above and below the beam pipe at the interaction point. Each scintillator has a size of 152 × 72 mm, and a thickness of 1.5 mm, through which almost all kaons pass. Two fast photomultipliers (Hamamatsu R4998) were optically coupled to the ends of each scintillator.

In this detector, charged kaon pairs were identified by a time-of-flight technique. The slow kaon pairs are clearly separated from fast minimum ionizing particles (MIPs), due to excellent time resolution (<100 ps FWHM) and the stability of the clock pulses (380 MHz RF) delivered by DAΦNE. A correlation of the time difference on the two scintillators is shown in Fig. 2. The K^+K^- pair production events are indicated. The ratio of kaon coincidences to MIPs during the kaonic helium measurements was about 20:1.

The kaonic helium X-rays were detected using recently-developed large area SDDs having an active area of 1 cm^2 and a thickness of 450 μm [12,13]. After detailed performance tests, 144 SDD chips were installed surrounding the target cell. The SDDs were cooled to a temperature of 170 K with a stability of ±0.5 K.