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PRECISE DETERMINATION OF KAONIC ^{4}He X-RAY ENERGY

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Abstract

The E570 experiment determined the strong-interaction shift of the kaonic ^{4}He $2p$ state by measuring the kaonic ^{4}He X-ray energy using Silicon Drift Detectors (SDDs). The obtained shift is 2±2 (stat.)±2 (syst.) eV. This value is in agreement with the theoretical calculations using the optical-potential models or the model predicting deeply-bound kaonic nuclear states, while it disagrees with the experimentally determined values in the past three experiments. Therefore, a long-standing discrepancy between the theories and experiments on the kaonic ^{4}He $2p$ state (kaonic helium puzzle) was eliminated for the first time.

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1 Introduction

The strong-interaction shift and width of the kaonic ^{4}He $2p$ state were measured in the three experiments from 1970's to 1980's [1]. The average of the shift is -43 ± 8 eV, while the analysis of the kaonic atom X-ray data with $Z > 2$ using the optical-potential model gives about 0 eV [2]. The recent calculation predicting deeply bound kaonic nuclear states shows that the shift can be possible within ± 10 eV [3]. This discrepancy between the experiments and theories is known as "kaonic helium puzzle".

Using a new technique to detect X-rays with high resolution in both energy and timing, we determined the most accurate value of the strong-interaction shift of the kaonic ^{4}He $2p$ state [4]. Here, the experimental results will be given briefly.

2 Experiment

The E570 experiment measured the energy of the kaonic ^{4}He X-ray transitions to the $2p$ state (Balmer lines) at the KEK-PS K5 beamline in Oct. 2005 and Dec. 2005. For this experiment, 8 Silicon Drift Detectors (SDDs), as well as pure Ti and Ni calibration foils, are installed in the E549 experimental setup [5].

As a target, super fluid liquid ^{4}He (0.145 g/cm^3) was used, and the target cell is cylindrical in shape (15 cm long and 20 cm in diameter). Each SDD has an effective area of 1 cm^2 and an active layer of 260 micron. The SDDs were cooled down to 83 K. Typical resolution of energy and time is about 185 eV (FWHM) at 6.4 keV and about 160 ns (rms).

The production points of the kaonic atoms were determined by detecting the secondary charged particles produced by the kaon reactions using the vertex chambers. The stopped kaon events inside the target cell were selected with the data of the vertex chambers and T0 counter [5].

Precise calibration of the X-ray energy spectra needs X-ray data with high statistics. The kaon beam contains a large number of high-energy pions ($\pi : K = 200 : 1$), which passed through the target cell and hit on the Ti and Ni foils. The pion-induced Ti/Ni X-ray lines detected by the SDDs with the self trigger were used as the calibration lines.

3 Data Analysis

Studies of the X-ray fit function are a key point to obtain the X-ray peak position with a precision of a few eV. The fit function for the pileup events was obtained using the Flash ADC data, in which a SDD signal shape was recorded. The fit function for the low-energy tails due to the incomplete charge collection was obtained by the fit to the Ti/Ni X-ray peaks. The effects of the incoherent (Compton) scattering on the He target were studied by simulating the X-ray data with GEANT4 including an extension package for the Low-Energy Compton Scattering (LECS) [6].

Table 1: Measured and calculated values [7] EM of the kaonic ^{4}He x-ray energy. The quoted error is statistical only.

Transition	$3d \to 2p$	$4d \to 2p$	$5d \to 2p$
Measured energy E_{exp} (eV)	6466.7 ± 2.5	8723.3 ± 4.6	9760.1 ± 7.7
EM calc. energy E_{calc} (eV)	6463.5	8721.7	9766.8

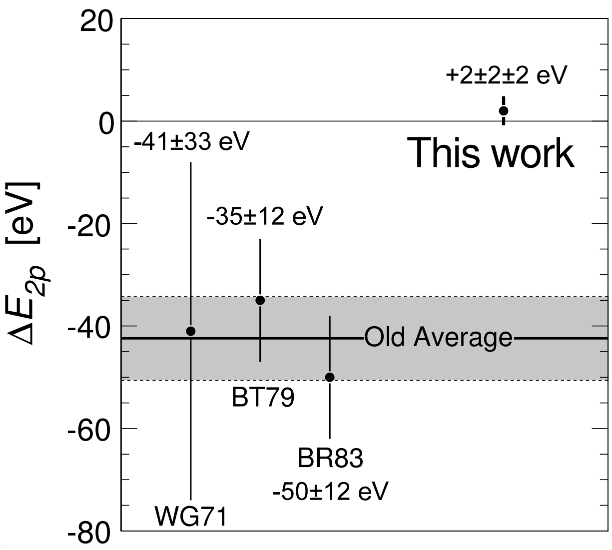

Figure 1: Comparison of experimental results for the hadronic shift DeltaE2p of the kaonic 4He 2p state

The measured values of the kaonic helium X-ray energy is given in Table 1, as well as the calculated values with the QED effects only [7]. The strong-interaction shift is obtained from the difference of the measured and calculated values: $\Delta E_{2p} = E_{exp} - E_{calc}$. Taking the average of the shifts of the three lines, we obtained the shift as $2 \pm 2 \pm 2$ eV. The comparison with the previous experiments is shown in Fig. 1.

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