Kaonic ^{3}He and ^{4}He X-ray measurements in SIDDHARTA

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The strong-interaction shift of kaonic ^{3}He and ^{4}He $2p$ states was measured using gaseous targets for the first time in the SIDDHARTA experiment. The determined shift of kaonic ^{4}He is much smaller than the values obtained in the experiments performed in 70's and 80's. Thus, the problems in kaonic helium (the "kaonic helium puzzle") was definitely solved by our measurements. The first observation of the kaonic ^{3}He X-rays was also achieved. The shift both of kaonic ^{3}He and ^{4}He was found to be as small as a few eV.

1 Introduction

There was a serious problem in the strong-interaction shift of the kaonic ^{4}He $2p$ level. The experimentally determined shift of the kaonic ^{4}He $3d \to 2p$ X-ray transition gave a large shift (about -40 eV) [1], while a predicted value deduced from optical models using the kaonic atom data of $Z \geqslant 3$ was about 0 eV [2]. Recently this abnormal $2p$ level shift was focused on theoretical studies related to kaonic nuclear states, where a shift as large as 10 eV was estimated [3]. However, no theory could obtain such a large measured shift of -40 eV. Therefore, confirmation measurements were awaited for a long time.

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The experiment by the KEK E570 collaboration determined the shift of $+2 \pm 2$ (stat) ± 2 (syst) eV [4], which disagreed with the previously measured value of -43 ± 8 eV.

Therefore, the SIDDHARTA experiment measured the kaonic ^{4}He X-rays to confirm the new result obtained by E570 [5]. In addition, the kaonic ^{3}He X-rays were measured using the same experimental apparatus, by replacing the target gas [6]. The latter was the world first's observation. This experiment provided new results on the kaon-helium interaction.

2 Experiment

The kaonic helium X-rays were measured in the SIDDHARTA experiment, which was performed in the DAΦNE e^+e^- collider at LNF (Italy). Charged kaon pairs produced by the annihilation of e^+e^- beams were detected by two scintillators installed in the interaction point. X-rays were detected using large area silicon drift detectors (SDDs) with a total area of 144 cm^2 [7]. Background events associated with the accelerator were rejected using the timing between the X-ray hits on the SDDs and the coincidence of K^+K^- pairs. A gaseous target was used in the measurement. The advantage was the negligible effect of Compton scattering in helium, where the contribution of the Compton tail was one of the difficulties in the analysis in the previous experiments [1,4].

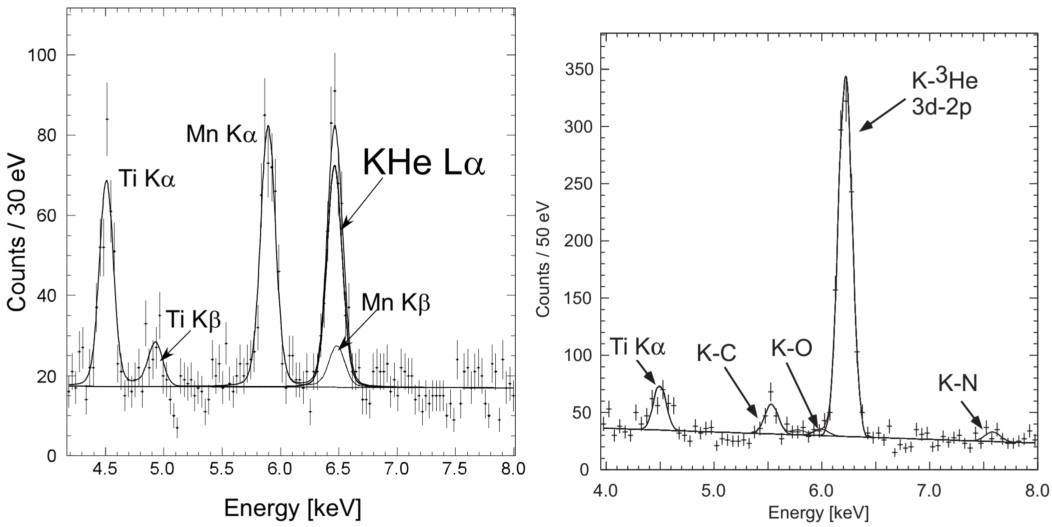

Figure 1: X-ray energy spectra of the $3d \rightarrow 2p$ transition of kaonic ^{4}He (left) and ^{3}He (right). The energy of these transitions were determined within an accuracy of a few eV.

The data of kaonic helium were taken during the beam time in 2009. The X-ray energy data of each SDD were calibrated using the X-ray tube installed in the setup. The background events uncorrelated to the timing of production of kaonic atoms were rejected by the analysis. A detailed description of the analysis can be found in [5–7].

Figure 1(left) shows the X-ray energy spectrum of kaonic ^{4}He [5]. The position of the kaonic helium X-rays are indicated in the figure. The Mn Kα and Kβ lines were originated from an ^{55}Fe source installed in the setup. These lines were used for calibration purpose and stability check of the SDDs [7]. The right figure shows the X-ray energy spectrum of kaonic ^{3}He. In addition to the kaonic ^{3}He X-ray line, some kaonic atom X-ray lines were seen, which were originated from the material (Kapton Polyimide) of the target cell window [6].

The strong interaction shift of the kaonic He $2p$ states was obtained from the fit of the kaonic He X-ray peaks. The determined shifts are shown in Fig. 2.

3 Conclusions

The SIDDHARTA experiment measured the strong-interaction shift both of the kaonic ^{3}He and ^{4}He $2p$ levels with an accuracy of several eV. They were measured using gaseous targets for the first time, and the world first's observation of kaonic ^{3}He X-rays was achieved.

A large shift of the order of -40 eV determined by the experiments performed in 70's and 80's was not obtained neither in kaonic ^{3}He nor kaonic ^{4}He. Both are consistent with 0 eV within the errors. The results agree with theoretical predictions determined from other kaonic atoms with $Z \geqslant 3$ using optical model approaches [2]. However, the SIDDHARTA results may indicate a possible isotope shift between kaonic ^{3}He and kaonic ^{4}He. Also, the theoretical prediction by [3] cannot be excluded within our accuracy.

More precise measurements are very important to understand the kaon-helium interaction. Such precision measurements can be performed in the J-PARC E17 experiment [8].

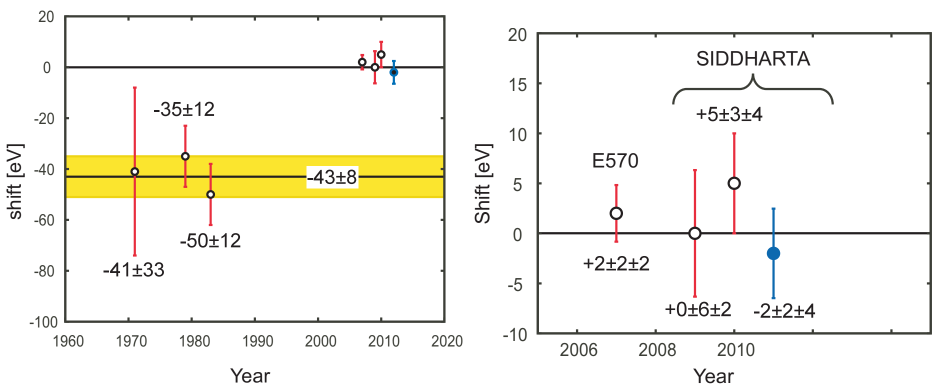

Figure 2: Comparison of experimental results. Open circle: K-^{4}He $2p$ state, Closed circle: K-^{3}He $2p$ state. A negative (positive) value of the shift shows a repulsive (attractive) shift.

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References

[1] S. Baird *et al.*, Nucl. Phys. A **392**, 297 (1983).

[2] C.J. Batty, Nucl. Phys. A **508**, 89c (1990).

[3] Y. Akaishi, *Proc. Inter. Conf. on Exotic Atoms (EXA05)*, Austrian Academy of Sciences Press, Vienna (2005), p. 45; `http://dx.doi.org/10.1553/exa05s45`.

[4] S. Okada *et al.*, Phys. Lett. B **653**, 387 (2007).

[5] SIDDHARTA Collaboration, Phys. Lett. B **681**, 310 (2009).

[6] SIDDHARTA Collaboration, Phys. Lett. B **697**, 199 (2011).

[7] M. Bazzi *et al.*, Nucl. Instr. and Meth. A **628**, 264 (2011).

[8] R. S. Hayano *et al.*, Proposal of J-PARC 50-GeV PS, *"Precision spectroscopy of Kaonic Helium 3* $3d \rightarrow 2p$ *X-rays"*, (2006).