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STUDY OF $\overline{K}$ BOUND STATES WITH THE FINUDA EXPERIMENT

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The FINUDA experiment is motivated to study hypernuclear physics with stopped K^- absorption process in good energy resolution. In addition, the kaon absorption on nuclei may produce kaon bound states. The simplest system ($\overline{K}NN$) is studied by detecting back-to-back pairs of a hyperon and a nucleon from its two-body decay.

1 Introduction

Akaishi and Yamazaki predicted the existence of nuclear $\overline{K}$ bound states in light nuclei [1]. They constructed a phenomenological $\overline{K}N$ potential, which reproduces experimental data such as $\overline{K}N$ scattering length and the level shift of the ground state of a kaonic hydrogen. They regarded $\Lambda(1405)$ as a bound state of an antikaon and a nucleon with the isospin 0, and this bound state can be reproduced by using their potential. According to their calculation, a kaon bound state lies below the $\Sigma\pi$ thresholds, which correspond to the binding energy (B) of $\sim 100\,\mathrm{MeV}$. Since the main decay channel $\overline{K}N \to \Sigma\pi$ is energetically forbidden, its decay width (Γ) becomes as narrow as $\sim 20\,\mathrm{MeV}$. For the lightest system of K^-pp, they obtained the binding energy of 48 MeV and the decay width of 61 MeV [2]. Recently, the calculations for this system are done in various papers [3,4,5,6,7,8]. A coupled channel approach by Shevchenko *et al.* gives $B = 55$–$70\,\mathrm{MeV}$ and $\Gamma = 95$–$110\,\mathrm{MeV}$ [3]. Many theoretical calculations support the existence of the K^-pp state with a rather broad width, as it lies above the $\Sigma\pi$ threshold in these calculations.

It is an open question whether a kaon bound state with narrow enough width to be observed experimentally exists or not. One of the reason is that the kaon-nucleus interaction is not well-established. A potential shallower than the phenomenological one, deduced by a chiral unitary approach also reasonably reproduces the X-ray data of kaonic atom. Experimental study on the bound state will give definite information on the strength of the potential.

If light kaon bound states are produced in kaon absorption process, the FINUDA experiment would be able to study its two-body decay by invariant-mass spectroscopy, such as:

$$K^- pp \to \Lambda + p \quad (\text{or } \Sigma^0 + p) \tag{1}$$

$$K^- pn \to \Lambda + n \quad (\text{or } \Sigma^0 + n) \tag{2}$$

$$K^- pn \to \Sigma^- + p \tag{3}$$

$$K^- ppn \to \Lambda + d. \tag{4}$$

2 FINUDA experiment

The main aim of the FINUDA experiment is to study hypernuclear physics with the (K^-_{stop}, π^-) reaction to produce Λ-hypernuclei. Slow kaons are abundantly supplied by an electron-position collider DAΦNE. Since a $\phi(1020)$ meson is produced almost at rest, the negative kaon from its two-body decay ($\phi \to K^+K^-$) is almost monochromatic at low momentum ($\sim 127\,\text{MeV}/c$). It can be stopped inside a thin nuclear target (0.2–0.3 g/cm^2).

Figure 1 shows a schematic view of the FINUDA spectrometer. Five kinds of targets (^{6}Li, ^{7}Li, ^{12}C, ^{27}Al and ^{51}V) were put around the beam pipe during the first data taking (2003–2004). Between the beam pipe and the targets, there were a barrel of 12 thin scintillator slabs (TOFINO) for identifying kaons and an octagonal array of silicon microstrip detectors (ISIM). Charged particles emitted after interactions were detected by another array of silicon microstrip detectors (OSIM), two layers of low-mass drift chambers (LMDC) and six layers of aluminized mylar straw tubes (axial and stereo, tilted by $\pm 12°$). The dE/dx in the OSIM detector was used for particle identification. External plastic scintillator slabs (TOFONE) were located in the outermost region for measuring the time-of-flight of both charged and neutral particles and for the trigger.

3 Correlation between Λ and proton

As seen in Figure 1, the spectrometer has a large acceptance, and is suitable to study the angular correlation between two particles. The opening angle

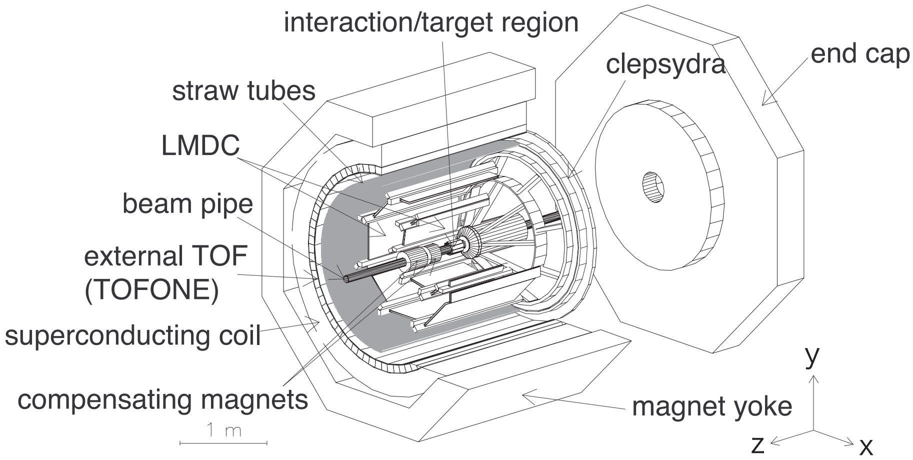

Figure 1. Schematic view of the FINUDA spectrometer.

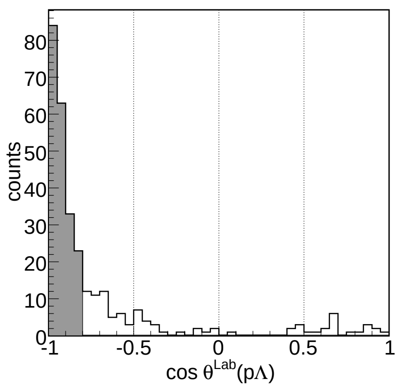

Figure 2. Opening angle distribution betwen a Λ and a proton from light nuclear targets (^{6}Li, ^{7}Li and ^{12}C)

distribution between a Λ and a proton, emitted from the K^- stopping point for light nuclear targets (^{6}Li, ^{7}Li and ^{12}C) is shown in Figure 2. A back-to-back component ($\cos\theta < -0.8$) is predominantly seen. To reduce backgrounds, the

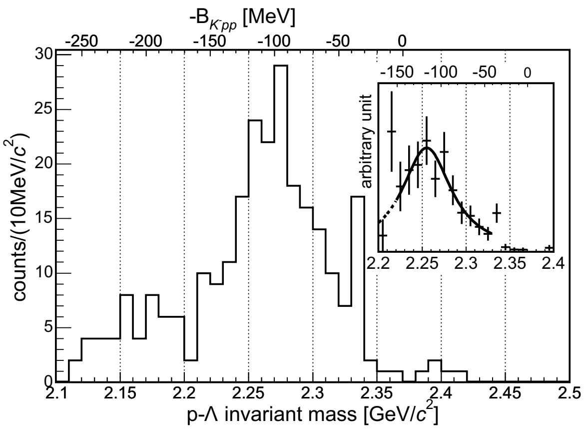

Figure 3. Invariant mass of back-to-back pairs of a Λ and a proton. The inset corresponds to the result after the acceptance correction for the well-defined good tracks.

shaded area is selected for further analysis.

Figure 3 shows the invariant mass distribution for such a back-to-back pair. A Λ and a proton are emitted after kaon absorption with two protons ($K^- +$ "pp" $\rightarrow \Lambda + p$), but the distribution shows a large mass shift from the threshold of $K^- + p + p$ ($2.37\,\mathrm{GeV/c^2}$). The spectrum after the acceptance correction is shown in the inset. If we assume naïve two-nucleon absorption process into $\Lambda + p$ with no final state interaction, the invariant mass would distribute just near the threshold. When the $\Sigma^0 + p$ channel is dominant, a mass shift occurs because we don't detect γ from $\Sigma^0 \rightarrow \Lambda + \gamma$ decay, but according to the old bubble chamber data by Katz *et al.* [9], the final state with Λ has larger branching ratio than the one with Σ. Magas *et al.* pointed out a possibility of the effect of the final state interaction after two-nucleon absorption [10]. The opening angle distribution between the two particles they obtained, however, has a larger fraction of non-back-to-back events than we observed [12].

We assume the back-to-back pairs of a Λ and a proton are the decay product of a kaon bound state K^-pp, produced in kaon absorption process. Then, we obtained the binding energy and decay width by fitting the global structure with a Lorenzian function, as $B = 115^{+6}_{-5}(\mathrm{stat})^{+3}_{-4}(\mathrm{stat})\,\mathrm{MeV}$ and $\Gamma = 67^{+14}_{-11}(\mathrm{stat})^{+2}_{-3}(\mathrm{syst})\,\mathrm{MeV}$, respectively [11].

4 $\Lambda - n$ and $\Sigma^- - p$ pairs

Since the FINUDA spectrometer can observe neutrons as well as charged particles, the correlations between a Λ and a neutron, or Σ^- ($\Sigma^- \rightarrow n + \pi^-$) and a proton can be studied as well. We observed similar back-to-back correlation for them. However, we could misidentify γ's as neutrons, which are mainly from the decay of stopped K^+ (for example, $K^+ \rightarrow \pi^+\pi^0$, followed by $\pi^0 \rightarrow 2\gamma$). In principle, we can estimate the level of this contamination by tagging μ^+ or π^+ from stopped K^+ decay.

These pairs are due to the kaon absorption by a pn pair inside a nucleus. Unlike the case of $\Lambda - p$ pairs, the NN pairs with both I=0 and 1 contribute. It will be interesting to compare the invariant-mass spectrum for each kind of pair, because the $\overline{K}N$ interaction has strong isospin dependence and therefore the kaon bound state will have isospin dependence, too.

5 $\Lambda - d$ pairs

In addition to the hyperon and nucleon pairs, we also observed a number of Lambda and deuteron pairs [13]. To our surprise, these pairs showed a clear back-to-back angular correlation as in the case of hyperon and nucleon pairs. The invariant mass of the Λ and deuteron system was investigated, and it showed a bump significantly below the $\overline{K}NNN$ binding threshold. It may indicate that the $\overline{K}NNN$ cluster is formed in the stopped K^- absorption process and decays into a Λ and a deuteron. Further data are needed to compare it with the $\overline{K}NNN$ systems.

6 Second data taking

We started the second data taking with much higher beam luminosity in October 2006 and successfully completed it in June 2007. We selected a different combination of targets (^{6}Li, ^{7}Li, ^{9}Be, ^{13}C and D_2O). We expect one order more statistics for $\Lambda + p$ events, for example. The detailed analysis on final states with neutrons will be possible, too.

7 Conclusions

The FINUDA experiment studies the $\overline{K}NN$ bound state by observing pairs of a hyperon and a nucleon, which could be the decay product of the bound state. As for $\Lambda - p$ pairs, we observed strong back-to-back correlations and their invariant mass were largely decreased about 100 MeV from the threshold. One interpretation is to assume that $K^- pp$ bound state with a large binding energy are produced in kaon absorption process. It is also important to compare the invariant-mass spectrum with different kinds of pairs ($\Lambda - n$ and $\Sigma^- - p$), because different isospin pairs contribute.

In order to get further understanding on the emitted hyperon-nucleon pairs, the analysis of new data with much higher statistics is on-going.

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