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SEARCH FOR DEEPLY-BOUND KAONIC NUCLEI AT FINUDA

The FINUDA Collaboration *

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ABSTRACT

By using the FINUDA detector, we carried out a search for deeply-bound kaonic nuclei. A preliminary result on the existence of the K^-pp bound system is reported.

1 Introduction

Recently, Akaishi and Yamazaki suggested the existence of deeply bound states of a kaon in light systems [1, 2, 3]. Their predictions were based on the $\overline{\mathrm{K}}\mathrm{N}$ interaction which is introduced to explain three experimental data such as the $\overline{\mathrm{K}}\mathrm{N}$ scattering length, the kaonic hydrogen (K^--p) atomic shift, and the binding energy and width of $\Lambda(1405)$, which is regarded as an $I = 0$ quasi-bound state of $\overline{\mathrm{K}}\mathrm{N}$. They calculated the binding energy and width for light systems and found that the strong attraction of $I = 0$ channel forbids the bound state decay via the main channel $\Sigma\pi$ energetically, and this fact results in its narrow width. Doté *et al.* also investigated the state with the method of antisymmetrized molecular dynamics and showed that its central density ρ becomes extremely high ($\rho > \rho_0$, where ρ_0 is the normal nuclear density) [4, 5]. While there still exist theoretical uncertainties whether the $\overline{K}$-nucleus potential is deep or shallow, it is important to experimentally investigate the possibility of producing such deeply bound states.

So far, two experimental groups have claimed the observation of the signatures for the deeply-bound states. Iwasaki *et al.* studied the $^4\mathrm{He}(K^-{}_{\mathrm{stop}},\ nX)$ reaction and observed K^-ppn state [6]. Further, they found a narrow peak in the proton spectrum in the $^4\mathrm{He}(K^-{}_{\mathrm{stop}},\ pX)$ reaction and assigned it to a strange tribaryon $^3S(3115)$ [7]. It is perhaps another kind of kaon bound state, K^-pnn. Kishimoto *et al.* found $^{15}\mathrm{O}K^-$ with the $^{16}\mathrm{O}(K^-,\ n)$ reaction at $P_{K^-} = 930\,\mathrm{MeV}/c$ [8].

Although the FINUDA detector was optimized for hypernuclear spectroscopy with $(K^-{}_{\mathrm{stop}},\ \pi^\pm)$ reactions [9], it also has advantages for the search for the deeply-bound kaonic states. We can apply missing-mass spectroscopy in the $(K^-{}_{\mathrm{stop}},\ n$ or $p)$ reactions for various kinds of targets (^{6}Li, ^{7}Li, ^{12}C, ^{27}Al, ^{51}V) at the same time. One of the great advantages in the FINUDA detector is the ability to identify the hyperons through their decays. In particular, a Λ hyperon mass can be reconstructed from the decay mode $\Lambda \to p + \pi^-$. It

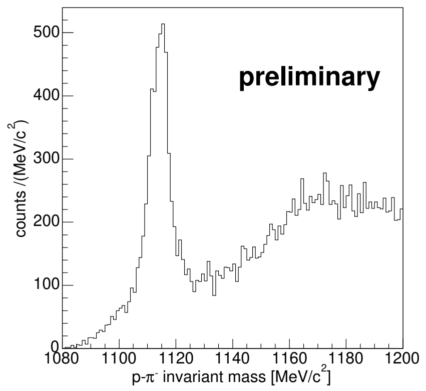

Figure 1: *Invariant mass of a proton and a π^- from K^- stopping point.*

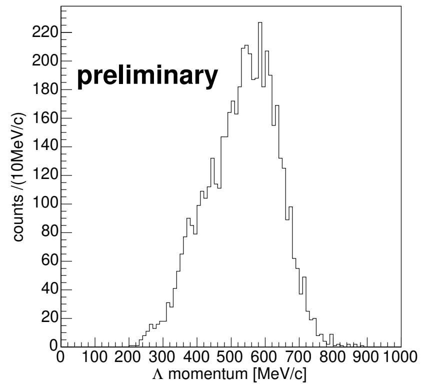

Figure 2: *Momentum distribution of Λ candidates.*

enables us not only to tag the decay of deeply-bound states, but also to apply invariant-mass spectroscopy [10] to directly search them.

In this report, we will discuss preliminary results on the invariant-mass spectroscopy of the K^-pp system, decaying in non-mesonic channels as follows:

$$K^-pp \to \left\{ \begin{array}{l} \Lambda + p \\ \Sigma^0 + p \end{array} \right. , \tag{1}$$

with the data obtained in the 2003–2004 data taking. The binding energy and width of the K^-pp system are calculated as $B = 48\,\mathrm{MeV}$ and $\Gamma = 61\,\mathrm{MeV}$ [11].

2 Identification of Λ

When a negative kaon stops at a nuclear target and is absorbed by the nucleus from its atomic orbit, it is known [12] that the two kinds of reactions predominantly occur, such as quasi-free hyperon production (K^-"N" $\to Y\pi$; $\sim 80\%$) and non-mesonic two-nucleon absorption (K^-"NN" $\to YN$; $\sim 20\%$), where Y represents a Λ or $\Sigma^{\pm/0}$ hyperon.

Here, we can identify the Λ by reconstructing the invariant mass $M(p\pi^-)$ of a proton and a negative pion with enough statistics and resolution, thanks to the good momentum resolution ($\Delta p/p \sim 0.3\%$[1] for $270\,\mathrm{MeV}/c$ π^-) and large

[1] At present, $\sim 0.6\%$ is achieved.

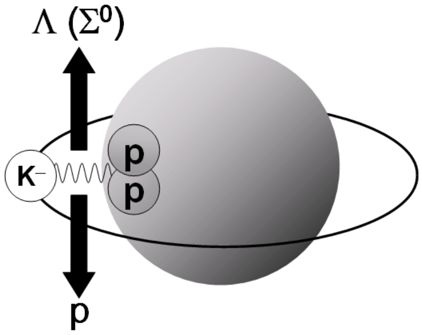

Figure 3: *An illustration of the K^-pp formation and the two-body decay mode, $\Lambda(\Sigma^0) + p$.*

acceptance ($\sim$ 70%) of FINUDA spectrometer. We used the sign of a track curvature and dE/dx in silicon microstrips for the particle identification. The invariant mass spectrum is shown in Fig. 1. The mass resolution of 8.6 MeV/c^2 (FWHM) for the Λ peak is almost consistent with that estimated by a Monte Carlo simulation. The resolution is limited by the momentum resolution for the slow pions (100–200 MeV/c) emitted from the Λ decay, because less hit points are available for such curly tracks. Please note that the FINUDA detector has a good acceptance and momentum resolution for the tracks with the momenta larger than 200 MeV/c.

Applying the mass gate for this spectrum as $|M(p\pi^-) - m_\Lambda| < 10\,\mathrm{MeV}/c^2$, we obtain the momentum distribution of Λ candidates as shown in Fig. 2. There are little events below 300 MeV/c because of the acceptance, particularly of pions, so that most of Λ's ($p_\Lambda \lesssim 400\,\mathrm{MeV}/c$) from the quasi-free production are not observed.

3 Invariant mass spectroscopy of K^-pp

The two-nucleon absorption process takes place at $\sim$ 20% for the stopped K^- reaction for a wide mass number range. For two-proton absorption K^-"pp" $\rightarrow$ $\Lambda + p$ or $\Sigma^0 + p$, we expect a hyperon and a nucleon are emitted in the final state almost back-to-back as shown in Fig. 3. Figure 4 is the angular distribution between a proton and a Λ observed in the present experiment. We can clearly

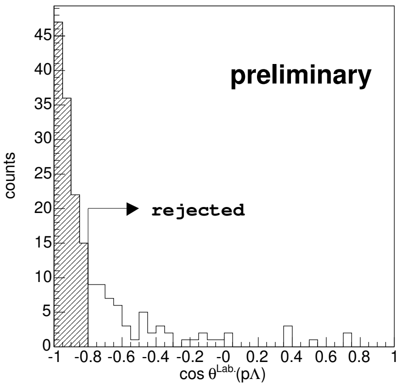

Figure 4: *Angular distribution between a proton and a Λ particle.*

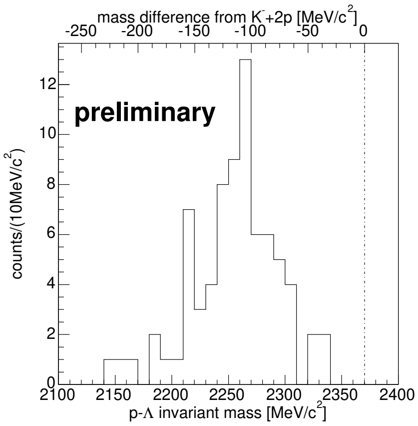

Figure 5: *Invariant mass of a proton and a Λ particle for $\cos\theta^{\mathrm{Lab.}}(p\Lambda) < -0.8$. The dotted line indicates the binding threshold of the K^-pp system.*

find the back-to-back correlation ($\cos\theta < -0.8$). This correlation is observed for all of our targets (^{6}Li–^{51}V). Then, the invariant mass of the $\Lambda - p$ system should distribute around the sum of $K^- + p + p$ mass, assuming that the two protons are uncorrelated at nuclear surface with small binding energies. Figure 5 shows the invariant mass distribution of the $\Lambda - p$ system. We find a broad bump peaked at about $2270\,\mathrm{MeV}/c^2$, which corresponds to the $\sim$ 100 MeV binding in the K^-pp system. We observed very few events in the unbound region, in fact. Even if the Λ we observed is all coming from the Σ^0 followed by the $\Lambda + \gamma$ decay, we expect the invariant mass would be shifted by only $\sim 74\,\mathrm{MeV}$ carried away with the γ-ray. It seems the current observation is far beyond this interpretation, and we know the Σ^0 contribution is only $\sim 20\%$ in ^{4}He [13]. Although the correction for the detector acceptance is still in progress, we think the present data strongly suggests the existence of the lightest kaon bound state K^-pp.

4 Summary

With the FINUDA spectrometer, we have succeeded to observe the reaction $K^-pp \rightarrow \Lambda + p$ (or $\Sigma^0 + p$) with explicitly observing a Λ and a proton in the back-to-back kinematics. The invariant mass distribution of the $\Lambda - p$ system strongly suggests a large amount of binding energy exists in the K^-pp system.

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References

1. Y. Akaishi and T. Yamazaki, Nucl. Phys. A **684** (2000) 409c.
2. Y. Akaishi and T. Yamazaki, Phys. Rev. C **65** (2002) 044005.
3. Y. Akaishi, in these proceedings.
4. A. Doté *et al.*, Phys. Lett. B **590** (2004) 51.
5. A. Doté *et al.*, nucl-th/0309062 (to be published in Phys. Rev. C).
6. M. Iwasaki *et al.*, nucl-ex/0310018.
7. T. Suzuki *et al.*, Phys. Lett. B **597** (2004) 263.
8. K. Kishimoto *et al.*, HYP2003 proceeding, to appear in Nucl. Phys. A.
9. M. Agnello *et al.* [FINUDA Collaboration], First Results of FINUDA on hypernuclear spectroscopy, these proceedings.
10. T. Yamazaki *et al.*, Phys. Lett. B **587** (2004) 167.
11. T. Yamazaki and Y. Akaishi, Phys. Lett. B **535** (2002) 70.
12. C. Vander Velde-Wilquet *et al.*, Nuovo Cimento **39A** (1977) 538.
13. P. A. Katz *et al.*, Phys. Rev. D **1** (1970) 1267.