Kaon two-nucleon absorption at rest with FINUDA

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Back-to-back pairs of a hyperon (Y) and a nucleon (N), from stopped kaon absorption on light nuclear targets, are studied with the FINUDA spectrometer. Such a pair with high momenta can be emitted from two nucleon absorption process (K^-"NN" $\rightarrow YN$). The invariant mass of the pair gives us additional information on the K^- + "NN" system and possible existence of the kaon-bound state with two nucleons.

§1. Introduction

The FINUDA experiment is originally dedicated to hypernuclear physics, using the ($K^-_{\rm stop}$, π^-) reaction to produce Λ-hypernuclei. Almost monochromatic K^- is supplied by the ϕ-factory DAΦNE, as a decay particle of a $\phi(1020)$ meson ($\phi \rightarrow K^+K^-$) with a very small momentum ($\sim 127\,{\rm MeV}/c$ from ϕ at rest). It can be easily stopped in a thin target (0.2–$0.3\,{\rm g/cm^2}$). In the first data-taking (2003-2004), we put five kinds of targets (^{6}Li, ^{7}Li, ^{12}C, ^{27}Al and ^{51}V) surrounding the beam pipe of DAΦNE.

Thanks to the large acceptance ($> 2\pi\,{\rm sr}$) of the spectrometer and the ability to detect both the charged and neutral particles with good particle identification and good momentum resolution for charged particles, we can study various topics related to the stopped K^- reaction.

When a kaon is absorbed into a nucleus from its atomic orbit, the kaon mainly interacts with one nucleon and emits a hyperon and a pion. According to old experiments,1) in the fraction of 15–20% per stopped K^-, the kaon interacts with multi nucleons and the final state does not include pions. It is not known how much three or more nucleons absorption contributes in case of kaon absorption, but by selecting back-to-back hyperon-nucleon pairs, we can select two-nucleon absorption process.

§2. Kaon-bound states

Akaishi and Yamazaki predicted the existence of nuclear $\overline{K}$ bound states with narrow decay width.2) They assumed $\Lambda(1405)$ is a $\overline{K}N$ bound state, and reconstructed a phenomenological potential from $\overline{K}N$ scattering length and the $2p \rightarrow 1s$ X-ray data of a kaonic hydrogen. Their calculation shows that the kaon-bound state ($B_{\overline{K}} \sim 100\,{\rm MeV}$) lies below the $\Sigma\pi$ threshold and the decay width becomes narrow since the main decay channel $\overline{K}N \rightarrow \Sigma\pi$ is energetically forbidden. While their optical potential is very deep, that obtained using the chiral unitary model is rather shallow,3),4) which also reproduces kaonic atom X-ray data. The existence or non-existence of the kaon-bound states and their widths are strongly related with the

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strength of the optical potential.

The binding energy (B) and decay width (Γ) of the lightest kaon-bound state K^-pp are calculated in various papers.[5)–9)] The calculation by Yamazaki and Akaishi with the ATMS method gives $B = 48\,\mathrm{MeV}$ and $\Gamma = 61\,\mathrm{MeV}$.[5)] A coupled channel approach is also applied by Shevchenco *et al.* and they obtained $B = 55$–$70\,\mathrm{MeV}$ and $\Gamma = 95$–$110\,\mathrm{MeV}$.[6)] Many theoretical calculations support the existence of such a bound state above the $\Sigma\pi$ threshold, and correspondingly its decay width is rather broad.

If a kaon-bound state with a few nucleons can be produced in kaon absorption process, the FINUDA experiment has the possibility to observe its non-mesonic two-body decay by invariant-mass spectroscopy, such as:

$$K^-pp \to \Lambda + p \quad (\text{or } \Sigma^0 + p) \tag{2·1}$$

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

$$K^-pn \to \Sigma^- + p \tag{2·3}$$

$$K^-ppn \to \Lambda + d. \tag{2·4}$$

§3. Correlation between Λ and proton

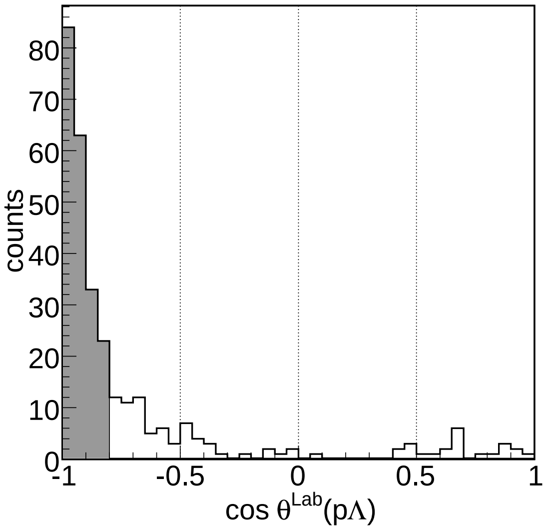

Fig. 1. Opening angle distribution between a Λ and a proton.

Figure 1 shows the opening angle distribution between a Λ and a proton from the K^- stopping vertex for the ^{6}Li, ^{7}Li and ^{12}C targets. While the spectrometer covers the wide angular range, a back-to-back component is predominantly seen. The back-to-back pairs ($\cos\theta < -0.8$) are selected for the further analysis. The invariant mass for the back-to-back pair is shown in Fig. 2. The distribution indicates the large mass shift from the threshold of K^-+p+p (2.37 GeV/c^2). The acceptance-corrected spectrum is also shown in the inset.

It is difficult to explain the mass shift with naïve two-nucleon absorption process ($K^- +$ "pp" $\to \Lambda + p$) with no final state interaction. If the $\Sigma^0 + p$ channel of the two-nucleon absorption is dominant, the mass shift is possible because of the missing energy of γ from $\Sigma^0 \to \Lambda+\gamma$ decay; however this assumption is inconsistent with the old bubble chamber data.[11] The possibility of the effect of the final state interaction is pointed out by Magas *et al.*,[12] while the calculated angular correlations with larger fractions of non-back-to-back events may be inconsistent with our observtion. Assuming the kaon-bound state K^-pp is produced, we can estimate the binding energy and the decay width by fitting the global structure with a Lorentzian function, as $B = 115^{+6}_{-5}$ (stat)$^{+3}_{-4}$ (syst) MeV and $\Gamma = 67^{+14}_{-11}$ (stat)$^{+2}_{-3}$ (syst) MeV, respectively.

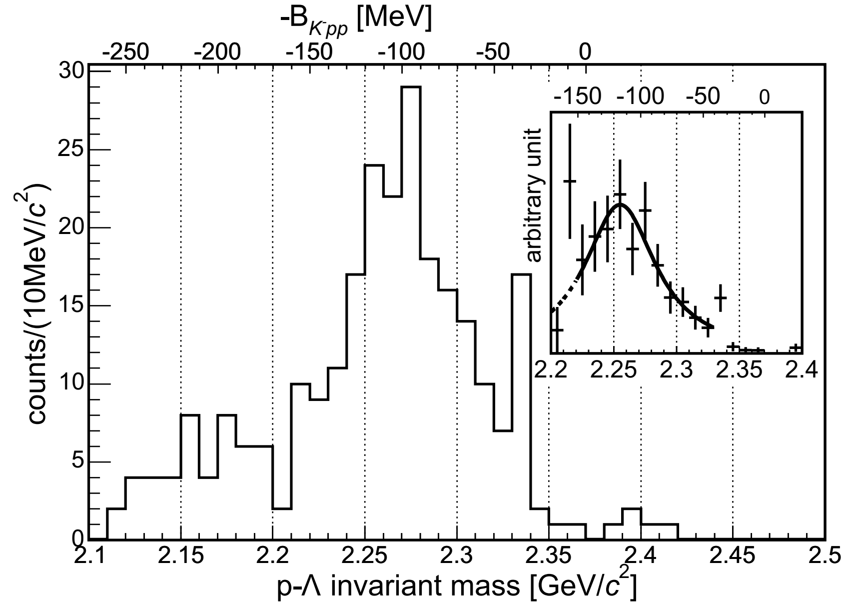

Fig. 2. Invariant mass of a Λ and a proton in back-to-back. The inset corresponds to the result after the acceptance correction for the well-defined good tracks.

§4. $\Lambda + n$ and $\Sigma^- + p$ pair

We also observed similar back-to-back correlations for $\Lambda + n$ and $\Sigma^- + p$ pairs as for $\Lambda + p$ by requiring one neutron in the final state. However, a lot of γ's are produced from π^0 decays and may contribute to the background for neutrons. Many π^0's are produced in the FINUDA expriment from the K^+ decay at rest (for example, $K^+ \to \pi^+\pi^0$). The level of the contamination can be estimated by tagging μ^+ or π^+ from K^+ decay.

We are now taking a new data with a different combination of targets (^{6}Li, ^{7}Li, ^{9}Be, ^{13}C and D$_2$O). We expect to have one order of magnitude more statistics. The comparison of three final states will be very useful in understanding the origin of the pairs, because $\Lambda + p$ pairs must come from the absorption by pp pairs, which has its isopsin 1, and the others from the absorption by pn pairs, which can have its isospin 0 or 1. Especially, the kaon-bound state should have isospin dependence, as the bare $\overline{K}N$ interaction is much stronger in $I = 0$ channel than in $I = 1$ channel.

§5. Conclusions

We study the hyperon and nuculeon pairs emitted from K^- stopping points. They have strong back-to-back correlation. As for $\Lambda + p$ pairs, a large mass shift as large as 100 MeV is seen when selecting the back-to-back pairs. One of the interpretations is to assume that a kaon-bound state K^-pp is produced in kaon absorption process. A new data with much higher statistics will enable us to compare the spectrum for $\Lambda + p$, $\Lambda + n$ and $\Sigma^- + p$. It will give the information on isospin structure of the kaon absorption process by two nucleons (both $I = 0$ and 1).

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