Letter of Intent for J-PARC 50 GeV Synchrotron

Decay Pion Spectroscopy of ${}^{5}_{\Lambda\Lambda}$H produced by ^{7}Li(K^-, K^+) reactions

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Abstract

Proposed is a novel method to produce a double-Λ hypernucleus without using nuclear emulsion. A Ξ^- bound in ^{6}He and a part of quasi-free Ξ^-'s, produced in ^{7}Li(K^-, K^+) reactions, are absorbed in the reaction point, and ${}^{5}_{\Lambda\Lambda}$H may be formed via $\Xi^- p \rightarrow \Lambda\Lambda$ conversion. Decay pion spectroscopy for ${}^{5}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ will be performed after event selection requiring a fast proton from non-mesonic weak decay of ${}^{5}_{\Lambda}$He. The experimental setup will be based on the Ξ-hypernuclear spectroscopy experiment E70; a new cylindrical detector system will be installed between the K1.8 beamline spectrometer and the S-2S spectrometer for detection of the decay pion and the proton.

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1 Physics Motivation

Experimental information on hypernuclei with strangeness $S = -2$, i.e. Ξ-hypernuclei and double-Λ hypernuclei, is still scarce, and J-PARC is the best place to investigate them extensively thanks to intense K^- beams. On the one hand, a high-resolution Ξ-hypernuclear spectroscopy is planned as the E70 (E05) experiment [1, 2]. As the first step, the ${}^{12}_{\Xi}$Be hypernucleus will be produced via the ^{12}C(K^-, K^+) reaction. On the other hand, the E07 experiment [3] has finished beam exposure on emulsion sheets, in which events with double-Λ hypernuclear production are being searched for. In this Letter of Intent, we propose a new experiment to produce and identify a particular double-Λ hypernucleus of ${}^{5}_{\Lambda\Lambda}$H in a different way without using the emulsion technique.

1.1 Four Methods for Double-Λ Hypernuclear Production

The emulsion technique has been used for more than half a century in search of double-Λ hypernuclei except for the BNL-AGS E885 and E906 experiments, whose detail will be given later. The first discovery of double-Λ hypernuclei was reported in 1963 by Danysz *et al.* [4] After the emulsion-counter hybrid method was established in the KEK-PS E176 experiment [5], the famous NAGARA event, exhibiting production and sequential decay of ${}^{6}_{\Lambda\Lambda}$He without any ambiguity, was discovered in the KEK-PS E373 experiment [6, 7]. In these experiments, a Ξ^- hyperon was produced in the quasi-free 'p'$(K^-, K^+)\Xi^-$ reaction, followed by its capture by a light nucleus (carbon, nitrogen, oxygen) in nuclear emulsion. After $\Xi^- p \to \Lambda\Lambda$ conversion took place in the nucleus, a double-Λ hypernucleus could be produced as a fragment. In this Letter of Intent, this process is referred to as **Ξ^- capture at rest**. Due to the fragmentation process, the species of produced double-Λ hypernuclei is far from unique. Nevertheless, a systematic study from ${}^{6}_{\Lambda\Lambda}$He to heavier ones such as ${}^{10}_{\Lambda\Lambda}$Be [7] and ${}^{13}_{\Lambda\Lambda}$B [5] has played an important role in exploring the $S = -2$ sector in hypernuclear physics and unravelling the $\Lambda\Lambda$ interaction [8]. In addition, the J-PARC E07 experiment is expected to yield one order of magnitude more double-Λ hypernuclear events, and discovery of a new double-Λ hypernucleus is foreseen.

Additionally, in the $\overline{\text{P}}$ANDA experiment at FAIR, this method will be utilized to perform a γ-ray spectroscopy of double-Λ hypernuclei [9]. Namely, a Ξ^- hyperon, produced in the $\overline{p} + A \to \Xi^- + \overline{\Xi}^+ + A'$ reaction, will be degraded by rescattering in the same target nucleus (see the next paragraph), and finally stop in a secondary target.

Another production mechanism of double-Λ hypernuclei (**quasi-free Ξ^- rescattering**) was proposed by Yamamoto *et al.* [10] Most of Ξ^- produced in the quasi-free (K^-,K^+) reaction on nuclei can escape from the target nucleus, while a part of Ξ^- will be absorbed in the same nucleus and a double-Λ compound nucleus is formed. They pointed out that a rescattering of the Ξ^- and a nucleon before absorption, resulting in slowdown of Ξ^- with knocking out the nucleon, enhances the formation probability of a double-Λ compound nucleus by more than one order of magnitude. For example, in case of a ^{9}Be target, a compound nucleus of $\left[{}^{8}_{\Lambda\Lambda}\text{He}\right]^*$ and $\left[{}^{8}_{\Lambda\Lambda}\text{H}\right]^*$ would be fragmented into normal nuclei, single-Λ hypernuclei, or double-Λ hypernuclei. It is found that the ${}^{5}_{\Lambda\Lambda}$H production probability is the largest in case of a ^{9}Be target, while the production probability of ${}^{6}_{\Lambda\Lambda}$He and ${}^{7}_{\Lambda\Lambda}$He increases for a target with a larger mass number (^{10}B, ^{11}B, ^{12}C). In addition, the pion energy distributions of decaying double-Λ hypernuclei and relevant single-Λ hypernuclei, which helps to identify the species of produced double-Λ hypernuclei, were also calculated.

Based on this theoretical work, the BNL-AGS E906 experiment [11] searched for light double-Λ

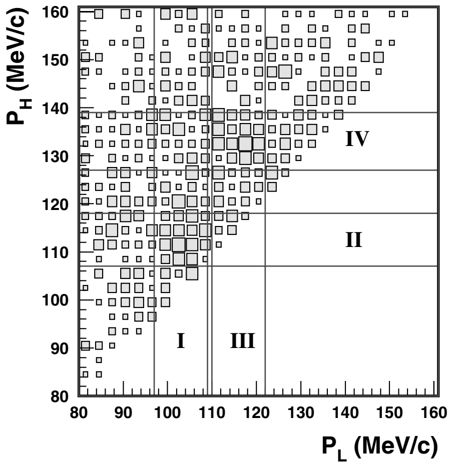

Figure 1: Correlation of two π^-'s momenta for Ξ^- production events. P_H and P_L correspond to pions with higher and lower momenta, respectively. Taken from Ref. [11].

hypernuclei with using a thick ^{9}Be target. Two π^-'s from sequential weak decay of a double-Λ hypernucleus were detected. Figure 1 shows a two-dimensional scatter plot of the momenta of two detected π^-'s. Two regions of event concentration near $(P_L, P_H) = (114, 133)$ and $(104, 114)$ (MeV$/c$) were attributed to originate from production of ${}^3_\Lambda$H + ${}^4_\Lambda$H (twin hypernuclei) and ${}^{\ 4}_{\Lambda\Lambda}$H (double-$\Lambda$ hypernuclei), respectively. Two-body decay of ${}^3_\Lambda\mathrm{H} \to {}^3\mathrm{He} + \pi^-$ and ${}^4_\Lambda\mathrm{H} \to {}^4\mathrm{He} + \pi^-$ generates monochromatic π^-'s with the momenta of 114.3 MeV$/c$ and 132.9 MeV$/c$. On the other hand, ${}^{\ 4}_{\Lambda\Lambda}$H is considered to decay as follows:

$$ {}^{\ 4}_{\Lambda\Lambda}\mathrm{H} \to {}^4_\Lambda\mathrm{He}^* + \pi^-, \tag{1} $$

$$ {}^4_\Lambda\mathrm{He}^* \to {}^3_\Lambda\mathrm{H} + p, \tag{2} $$

$$ {}^3_\Lambda\mathrm{H} \to {}^3\mathrm{He} + \pi^-, \tag{3} $$

where the resonance of ${}^4_\Lambda$He* had not been reported before. The bond energy of $\Delta B_{\Lambda\Lambda} \equiv B_{\Lambda\Lambda}({}^{\ 4}_{\Lambda\Lambda}\mathrm{H}) - 2B_\Lambda({}^3_\Lambda\mathrm{H})$, where $B_{\Lambda\Lambda}$ and B_Λ denote the binding energy of two Λ's and a single Λ, respectively, was not determined due to unknown excitation energy of ${}^4_\Lambda$He* under consideration. A proposal of the P961R experiment [12], in which the target was to be replaced by ^{7}Li and the experimental setup was to be improved in view of the resolution and the yield, was submitted, but unfortunately the experiment was not realized because the AGS operation was cancelled except for the RHIC experiments.

As for the event concentration near (104, 114) (MeV$/c$), there are two different interpretations to attribute it to twin hypernuclei of ${}^3_\Lambda\mathrm{H} + {}^6_\Lambda\mathrm{He}$ [13], and different double-Λ hypernuclei ${}^{\ 7}_{\Lambda\Lambda}$He [14]. The momentum distributions of the two pions in each scenario are different one by one, but our current understanding does not allow us to rule out all but one scenario. As far as the ^{9}Be target is considered, a double-Λ hypernucleus ${}^{\ A}_{\Lambda\Lambda}Z$ or twin hypernuclei ${}^{A_1}_{\Lambda}Z_1 + {}^{A_2}_{\Lambda}Z_2$ produced as a fragment of a double-Λ compound nucleus of $\left[{}^{\ 8}_{\Lambda\Lambda}\mathrm{He}\right]^*$ and $\left[{}^{\ 8}_{\Lambda\Lambda}\mathrm{H}\right]^*$ must satisfy ($A \leq 7$ and $Z \leq 2$)[1] or ($A_1 + A_2 \leq 8$ and $Z_1 = Z_2 = 1$)[2]. The condition is slightly relaxed, if Ξ^- capture at rest by other nucleus is considered, as ($A \leq 9$ and $Z \leq 3$) or ($A_1 + A_2 \leq 10$ and $Z_1 + Z_2 \leq 3$). Needless to say, all the three scenarios fulfill these conditions.

[1]At least one nucleon must be evaporated from the compound nucleus because of the conservation of energy, hence $A < 8$.
[2]Fragmentation into twin hypernuclei with nothing else, i.e. $A_1 + A_2 = 8$, is possible.

This constraint will be more strict when a target with a smaller mass number is adopted. For a ^{7}Li target, the constraint will be ($A \le 7$ and $Z \le 2$) or ($A_1 + A_2 \le 8$ and $Z_1 = Z_2 = 1$). If we ignore the production via Ξ^- capture at rest due to a smaller stopping probability of Ξ^- in lithium with a smaller density (0.53 g/cm^3) compared to beryllium (1.85 g/cm^3), only the production of a double-Λ hypernuclei with $A \le 5$ and $Z = 1$ from a fragmentation of $\left[{}^{6}_{\Lambda\Lambda}\mathrm{H}\right]^*$ is allowed and twin hypernuclei cannot be formed[3]. Therefore, in order to obtain more robust identification of double-Λ hypernuclei, an experiment with a ^{7}Li target is highly desired.

Third method to form a double-Λ hypernuclear system is **direct production** by use of the (K^-,K^+) reaction. Harada *et al.* theoretically investigated a one-step $^{16}\mathrm{O}(K^-, K^+)\,{}^{16}_{\Lambda\Lambda}\mathrm{C}$ reaction, in which two Λ's are created via Ξ^- doorways through $\Xi^- p$-$\Lambda\Lambda$ conversion [16]. The production cross section depends on the ΞN-$\Lambda\Lambda$ coupling strength or the Ξ^- admixture probability of the double-Λ hypernuclei. From the experimental side, an upper limit of the ${}^{12}_{\Lambda\Lambda}\mathrm{Be}$ production cross section in the $^{12}\mathrm{C}(K^-, K^+)$ reaction was obtained in the BNL-AGS E885 experiment [17]. In addition, an experiment with the S-2S spectrometer is planned as one of possible future plans [18]. Much better energy resolution compared to the previous experiment at BNL will improve the sensitivity.

Yet another method, named **Ξ-hypernuclear decay** in this Letter of Intent, was proposed by Kumagai-Fuse and Akaishi [19]. They pointed out that a Ξ hypernucleus ${}^{7}_{\Xi^-}\mathrm{H}$ will decay into ${}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$ with a very large branching ratio of about 90%. The possible decay modes of ${}^{7}_{\Xi^-}\mathrm{H}$ are

$$
\begin{aligned}
{}^{7}_{\Xi^-}\mathrm{H} &\to {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n + 11\,\mathrm{MeV}, &(4)\\
&\to {}^{4}_{\Lambda}\mathrm{H} + \Lambda + 2n + 7\,\mathrm{MeV}, &(5)\\
&\to {}^{4}_{\Lambda}\mathrm{H}^* + \Lambda + 2n + 6\,\mathrm{MeV}, &(6)\\
&\to {}^{3}_{\Lambda}\mathrm{H} + 2\Lambda + 2n + 5\,\mathrm{MeV}, &(7)
\end{aligned}
$$

where the reaction Q-values are only approximate because of assumptions on the binding energies of ${}^{7}_{\Xi^-}\mathrm{H}$ and ${}^{5}_{\Lambda\Lambda}\mathrm{H}$. A small Q-value disfavors decay into many body because of the available phase space, and as a result, the three-body decay (4) will be the dominant channel. According to Ref. [19], the branching ratio reaches as large as 90%. It is worth stressing that a small Q-value is owed to a substantial cancellation between the energy released in $\Xi^- p \to \Lambda\Lambda$ conversion and the neutron separation energy of ^{4}He in the ${}^{7}_{\Xi^-}\mathrm{H} \to {}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$ (i.e. $[\alpha nn\Xi^-] \to [t\Lambda\Lambda] + 2n$) reaction.

Inspired by this theoretical calculation, we have conceived an experimental concept to populate ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ from decay of ${}^{7}_{\Xi^-}\mathrm{H}$ produced in the $^7\mathrm{Li}(K^-, K^+)$ reaction. Unlike Ξ^- capture at rest in the emulsion-counter hybrid method, a particular double-Λ hypernuclei of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ is expected to be selectively produced in Ξ-hypernuclear decay and quasi-free Ξ^- rescattering with a ^{7}Li target.

1.2 $\Lambda\Lambda$-ΞN Mixing in ${}^{5}_{\Lambda\Lambda}\mathrm{H}$

One of the most important features in ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ in comparison with ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ is the role of the $\Lambda\Lambda$-ΞN mixing [20]. While the two protons and two neutrons occupy the 0s shell and the $\Lambda\Lambda$-ΞN mixing is Pauli-suppressed in ${}^{6}_{\Lambda\Lambda}\mathrm{He}$, a lack of one proton in the 0s shell allows the $\Lambda\Lambda$-ΞN mixing, in which the second proton can occupy the 0s shell. An enhancement of the $\Lambda\Lambda$ bonding energy due to the $\Lambda\Lambda$-ΞN mixing was stressed by Myint *et al.* [21], and independently by Lanskoy–Yamamoto [22] and by Yamamoto–Rijken [23]. A full-coupled channel calculation resulted in a large Ξ probability even

[3]Neutral single- and double-Λ hypernuclei such as $nn\Lambda$ (recently reported by the HypHI experiment [15]) and $nn\Lambda\Lambda$, as well as a bound H-dibaryon are not considered in this Letter of Intent.

in case of a weak $\Lambda\Lambda$-ΞN potential [24]. In contrast, Filikhin *et al.* argued that the $\Lambda\Lambda$-ΞN mixing effect is not significantly different between ${}^{5}_{\Lambda\Lambda}$H and ${}^{6}_{\Lambda\Lambda}$He [25].

Therefore, a precise determination of the bond energy of ${}^{5}_{\Lambda\Lambda}$H, which is the main motivation of this Letter of Interest, is of great importance. At least, all these theoretical calculations support the existence of particle-stable ${}^{5}_{\Lambda\Lambda}$H against the ${}^{4}_{\Lambda}$H + Λ channel, with the $\Lambda\Lambda$ bond energy more than 0.5 MeV [26]. It should be noted that these calculations relied on the old value for the binding energy of ${}^{6}_{\Lambda\Lambda}$He [6], 0.34 MeV larger than the updated value [7], and that an up-to-date calculation for ${}^{5}_{\Lambda\Lambda}$H and ${}^{6}_{\Lambda\Lambda}$He with a weaker $\Lambda\Lambda$ interaction is awaited.

1.3 Perspective

"Mass production" of double-Λ hypernuclei in a counter experiment will enable us to derive not only the $\Lambda\Lambda$ bond energy, but also the lifetime and the branching ratio of weak decay modes, which cannot be investigated in emulsion-based experiments. While production, structure, and decay of single-Λ hypernuclei have been studied for a long time in great detail [26, 27, 28, 29], available quantitative information on double-Λ hypernuclei is limited to the bond energy. The ${}^{5}_{\Lambda\Lambda}$H production experiment is expected to serve as a step forward to detailed understanding of double-Λ hypernuclear systems.

2 Experimental Principle

We will consider two kinds of production methods, i) Ξ-hypernuclear decay and ii) quasi-free Ξ^- rescattering, in order to produce ${}^{5}_{\Lambda\Lambda}$H from a ^{7}Li target. A Ξ^- hyperon can be produced by the ^{7}Li(K^-, K^+) reaction. Events below and above the Ξ^- + ^{6}He$_{\text{g.s.}}$ threshold in the missing-mass spectrum for this reaction correspond to pruduction of ${}^{7}_{\Xi^-}$H and quasi-free Ξ production, respectively (see Fig. 4). More detail will be given in Section 2.1. In practice, a finite missing-mass resolution obscures the distinction between them, and this is why we would like to use the S-2S spectrometer instead of the KURAMA spectrometer, in spite of a smaller acceptance.

Following the discussion in Sect. 1.1, most of bound ${}^{7}_{\Xi^-}$H decays into ${}^{5}_{\Lambda\Lambda}$H, whereas a part of quasi-free Ξ^-, rescattered and absorbed by the same nucleus, forms ${}^{5}_{\Lambda\Lambda}$H as a fragment of a double-Λ compound nucleus. In both cases, identification of ${}^{5}_{\Lambda\Lambda}$H with rejection of background such as ${}^{4}_{\Lambda}$H + Λ is virtually important to confirm the existence of ${}^{5}_{\Lambda\Lambda}$H and derive the $\Lambda\Lambda$ bond energy by means of decay pion spectroscopy, which is the initial goal of this experiment. The procedure will be thoroughly explained in Sect. 2.2.

Figures 2 and 3 depict flow charts of ${}^{5}_{\Lambda\Lambda}$H production and decay, exhibiting the experimental principle. After event selection requiring a fast proton ($\gtrsim$ 20 MeV) in coincidence, decay pion spectroscopy for the two-body decay of ${}^{5}_{\Lambda\Lambda}$H, i.e. ${}^{5}_{\Lambda\Lambda}$H $\to$ ${}^{5}_{\Lambda}$He + π^-, will be performed. The partial decay width was calculated to be $0.38\Gamma_\Lambda$ compared to the total decay width of $1.30\Gamma_\Lambda$ [10], where Γ_Λ is the free-Λ decay width. As the lifetime of ${}^{5}_{\Lambda\Lambda}$H is long enough to stop inside the target before its decay, the measurement of the π^- momentum will determine the mass of ${}^{5}_{\Lambda\Lambda}$H, hence its $\Lambda\Lambda$ bond energy.

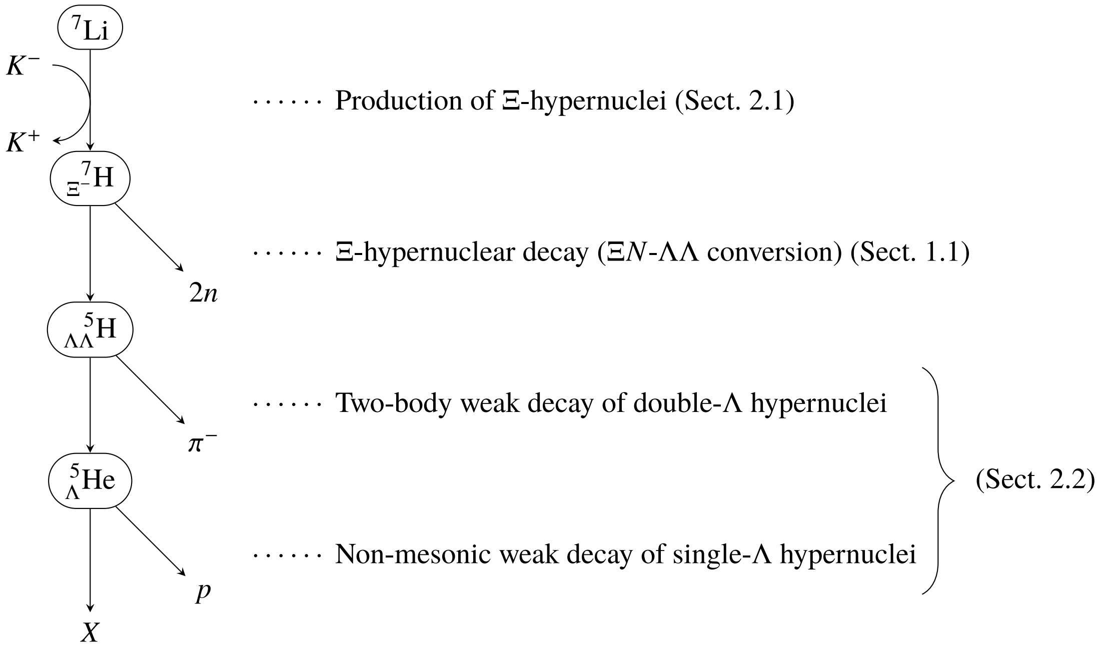

Figure 2: A flow chart for the Ξ-hypernuclear decay method

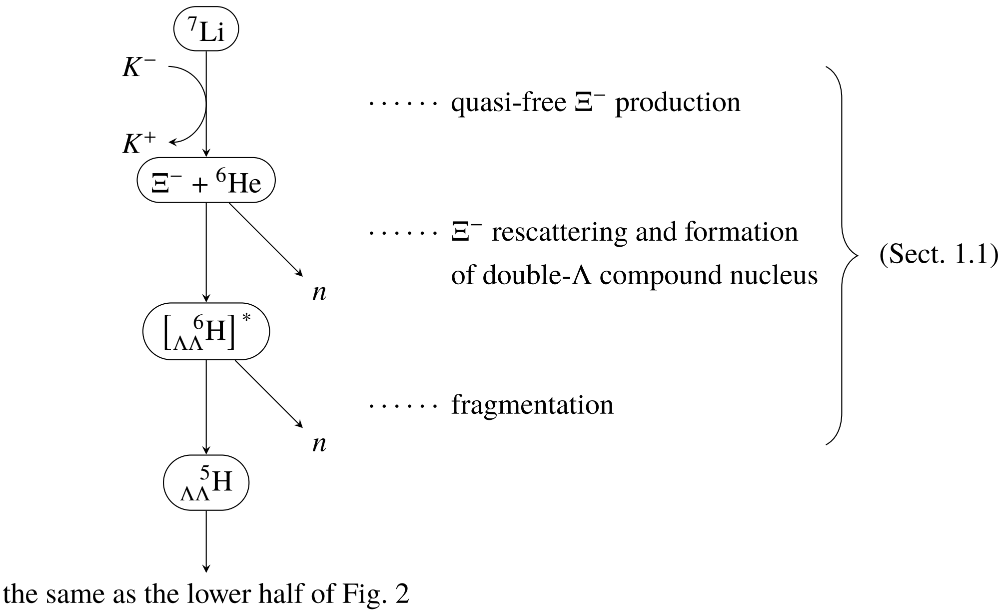

Figure 3: A flow chart for the quasi-free Ξ^- rescattering method.

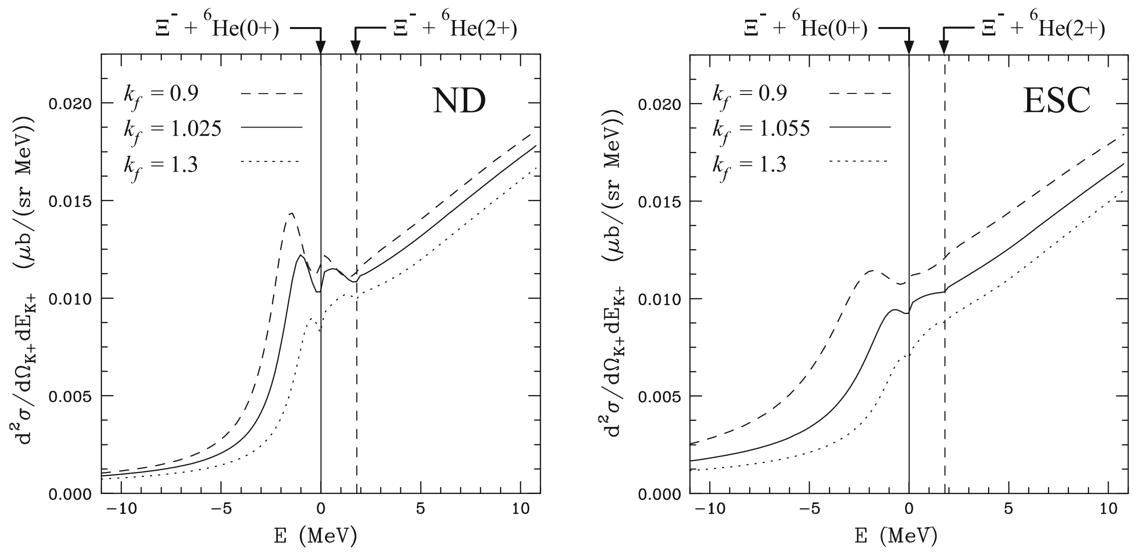

Figure 4: Theoretically calculated (K^-, K^+) spectrum for two kinds of ΞN interaction models (ND and ESC). k_f is the Fermi momentum of nuclear matter, and is chosen within a reasonable range. Taken from Ref. [30].

2.1 Production of Ξ-hypernuclei

A Ξ-hypernucleus, ${}^{7}_{\Xi^-}\mathrm{H}$, will be populated by the ${}^{7}\mathrm{Li}(K^-, K^+)$ reaction. The reaction is essentially the same as that to be investigated in the E70 (E05) experiment [1, 2], except for the target nucleus, hence the same setup, i.e. the S-2S spectrometer together with the K1.8 beamline, can be adopted.

Koike and Hiyama calculated the spectrum of the ${}^{7}\mathrm{Li}(K^-, K^+)$ reaction, at the beam momentum $p_{K^-} = 1.65\,\mathrm{GeV}/c$ and the scattering angle $\theta_{K^+} = 0°$, as shown in Fig. 4 [30]. A clear peak of the bound ${}^{7}_{\Xi^-}\mathrm{H}$, whose structure was already investigated in Ref. [31], is seen except for the case of the ESC model with $k_f = 1.3$.

2.2 Identification of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$

As described in Sect. 1.1, ${}^{7}_{\Xi^-}\mathrm{H}$ is supposed to decay predominantly into ${}^{5}_{\Lambda\Lambda}\mathrm{H} + 2n$. However, other decay channels such as ${}^{4}_{\Lambda}\mathrm{H} + \Lambda + 2n$ are also allowed energetically. The same holds for the quasi-free Ξ^- rescattering. Thus, an experimental confirmation and event selection of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ production by using information on decay particles of ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ is mandatory.

Similar to the case for weak decay of single-Λ hypernuclei, ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ is expected to decay as follows:

$$ {}^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-, \tag{8} $$

$$ \to {}^{4}_{\Lambda}\mathrm{H} + p + \pi^-, \tag{9} $$

$$ \to {}^{4}_{\Lambda}\mathrm{H} + n + \pi^0. \tag{10} $$

Among them, the two-body decay (8) with the momentum of emitted $\pi^- \approx 133\,\mathrm{MeV}/c$ is of interest for decay pion spectroscopy. Unfortunately, it is very close to that in ${}^{4}_{\Lambda}\mathrm{H} \to {}^{4}\mathrm{He} + \pi^-$ decay ($132.9\,\mathrm{MeV}/c$ [32]), because the recombination of triton (in ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ or ${}^{4}_{\Lambda}\mathrm{H}$) with proton (from Λ decay) results in the formation of an α particle with a large energy released. Their distinction without further

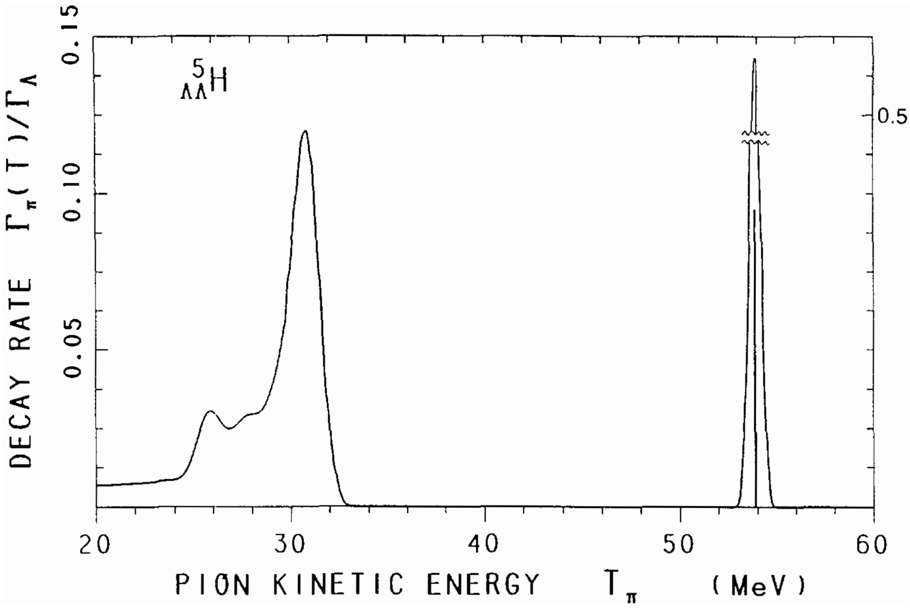

Figure 5: Theoretically calculated π^- energy spectrum from ${}_{\Lambda\Lambda}^{5}$H decay. Taken from Ref. [10].

information is very challenging from the point of view of experimental resolution. It should be noted that the π^- momentum in decay of other single Λ-hypernuclei or three-body decay of ${}_{\Lambda\Lambda}^{5}$H does not exceed 120 MeV/c (cf. Fig. 8 in Ref. [10]), and that a faster π^- must stem from either ${}_{\Lambda\Lambda}^{5}$H or ${}_{\Lambda}^{4}$H.

Consequently, we need to take into account a sequential weak decay of ${}_{\Lambda\Lambda}^{5}$H, starting from the two-body decay (8). The weak decay of ${}_{\Lambda}^{5}$He was investigated by the KEK-PS E462 experiment and the FINUDA experiment. In general, weak decay of Λ hypernuclei is categorized into two types: mesonic decay ($\Lambda \to N\pi$) and non-mesonic decay ($\Lambda N \to NN$ or $\Lambda NN \to NNN$).

In contrast to the identification of ${}_{\Lambda\Lambda}^{4}$H in the BNL-AGS E906 experiment, the use of the following mesonic decay of ${}_{\Lambda}^{5}$He

$$ {}_{\Lambda}^{5}\mathrm{He} \to {}^{4}\mathrm{He} + p + \pi^- \tag{11} $$

will complicate the analysis of decay pion spectroscopy, because two different sequential decay modes give a pair of π^- with almost the same kinetic energies. As shown in Fig. 6, the energy distribution of π^- in the ${}_{\Lambda}^{5}\mathrm{He} \to {}^{4}\mathrm{He}+p+\pi^-$ decay [33], centered at 32 MeV, resembles that in the ${}_{\Lambda\Lambda}^{5}\mathrm{H} \to {}_{\Lambda}^{4}\mathrm{H}+p+\pi^-$ decay, indicated by the left component in Fig. 5. Furthermore, approximately half of ${}_{\Lambda}^{4}$H decay into ^{4}He + π^-, emitting a π^- with almost the same momentum as that from the two-body decay (8) of ${}_{\Lambda\Lambda}^{5}$H. Therefore, the observation of two π^-'s with the momenta of $\approx$ 99 MeV/c and $\approx$ 133 MeV/c may indicate the production of ${}_{\Lambda\Lambda}^{5}$H, aside from another process of ${}_{\Xi^-}^{7}\mathrm{H} \to {}_{\Lambda}^{4}\mathrm{H} + \Lambda + 2n$, while the determination of the binding energy ($B_{\Lambda\Lambda}$) of ${}_{\Lambda\Lambda}^{5}$H by using the π^- in the two-body decay (8) is very difficult.

This overlapping problem may be avoided by looking into non-mesonic weak decay without emitting a pion:

$$ {}_{\Lambda}^{5}\mathrm{He} \to p + n + {}^{3}\mathrm{H}. \tag{12} $$

In non-mesonic weak decay, a virtual pion from $\Lambda \to N\pi$ decay is absorbed by one or more nucleons, and a large energy of 176 MeV is released. The proton energy spectrum was investigated by the

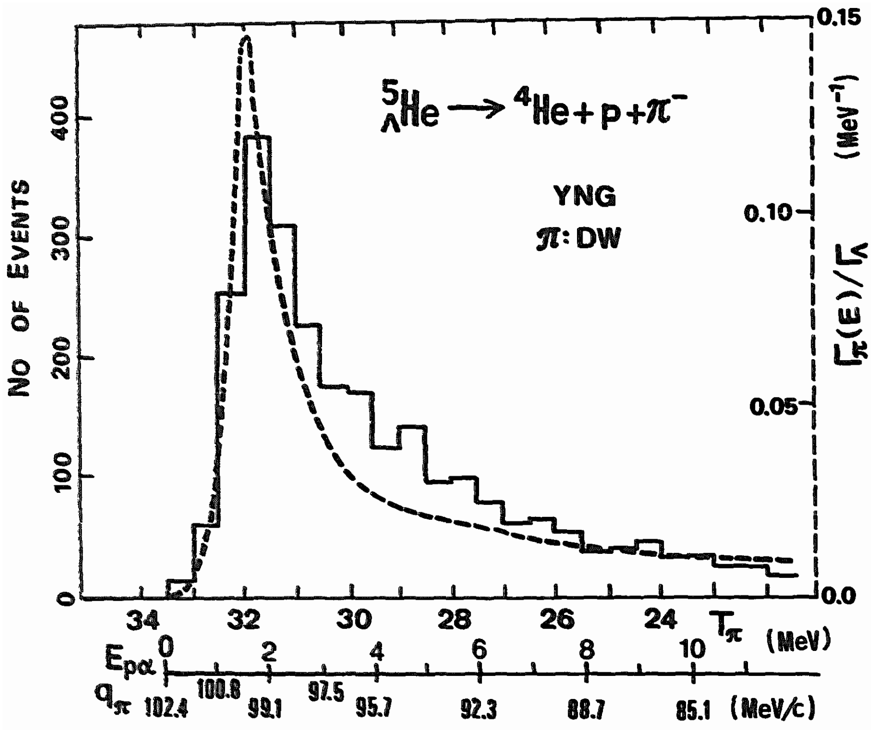

Figure 6: Theoretically calculated π^- energy spectrum (dashed line) and experimental one (solid line) in $^5_\Lambda\text{He} \to {}^4\text{He} + p + \pi^-$ decay. Taken from Ref. [33].

KEK-PS E462 experiment [34] and the FINUDA experiment [35], and it exhibits a peak around 70 MeV, as shown in Fig. 7.

Let us consider a case of $^4_\Lambda$H production, emitting a π^- whose momentum is comparable to that from $^{\ 5}_{\Lambda\Lambda}$H . It must originate from the decay of $^{\ 7}_{\Xi^-}$H [(5), (6)], the fragmentation of $\left[^{\ 6}_{\Lambda\Lambda}\text{H}\right]^*$ into $^4_\Lambda\text{H} + \Lambda + n$, or the decay of $^{\ 5}_{\Lambda\Lambda}$H [(9), (10)]. In any case, the kinetic energy of the accompanied proton, which exists except for (10), cannot be as large as that from non-mesonic weak decay of $^5_\Lambda$He. By requiring a fast proton ($\gtrsim$ 20 MeV) in coincidence with a fast π^-, all the background events are expected to be removed. At the same time, in-flight decay of $\Xi^- \to \Lambda + \pi^- \to p + \pi^- + \pi^-$, which was the main source of background in the $2\pi^-$ event samples of the BNL-AGS E906 experiment, may be distinguished, because the decay proton is concentrated in the forward direction. A quantitative study based on a Monte Carlo simulation is in progress.

In conclusion, the binding energy of $^{\ 5}_{\Lambda\Lambda}$H or the $\Lambda\Lambda$ bond energy can be estimated by decay pion spectroscopy for $^{\ 5}_{\Lambda\Lambda}$H, by measuring the momentum of a π^- with a high resolution and tagging a fast proton at the same time. The coicnidence of the fast proton guarantees that the π^- originates exclusively from the two-body decay of $^{\ 5}_{\Lambda\Lambda}$H (8). For this purpose, we plan to build and install a new cylindrical detector system with a cylindrical drift chamber or time projection chamber inside it, surrounding the ^{7}Li target.

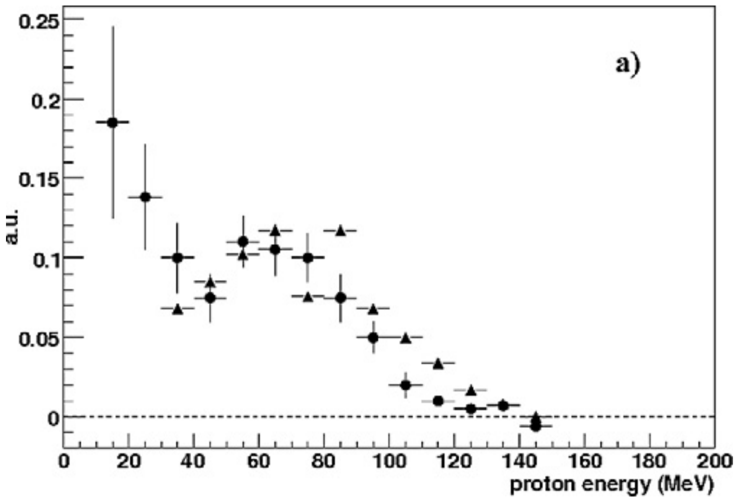

Figure 7: Proton energy spectrum from proton-induced non-mesonic weak decay of ${}^{5}_{\Lambda}$He. Dots and triangles correspond to the FINUDA and KEK experiments, respectively. Taken from Ref. [35].

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