

A spectroscopic study of ${}_{\Xi}^{10}\text{Li}$ hypernucleus via the ${}^{10}\text{B}(K^-, K^+)X$ reaction

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Abstract. We are planning a ${}_{\Xi}^{10}\text{Li}$ production experiment using the ${}^{10}\text{B}(K^-, K^+)X$ reaction at the J-PARC, K1.8 beamline. We perform spectroscopy of missing masses using the $S - 2S$ spectrometer, which can achieve high resolution. Since the cross section of Ξ -hypernuclei is very small, we would like to use a thick target. To ensure the missing mass resolution, we propose a semi-inclusive method using a tracking device to detect the decay particles from Ξ -hypernuclei.

1 Introduction

The Ξ -nucleon interaction is the last piece of the nuclear force study that has been extended to the strange quark, and the Ξ -hypernuclear spectroscopy experiment will provide us with rich information. We are planning a series of Ξ -hypernuclear spectroscopy experiments using (K^-, K^+) reactions at the Japan Proton Accelerator Re-search Complex (J-PARC), K1.8 beamline.

As the first experiment, a ${}^{12}\text{Be}$ spectroscopy experiment using a CH_2 active target is planned. In order to further investigate the Ξ -nucleon interaction precisely, it is necessary to systematically measure the binding energies of various Ξ -hypernuclei using different targets. We are particularly interested in spectroscopic experiments on ${}_{\Xi}^{10}\text{Li}$. ${}_{\Xi}^{10}\text{Li}$ consists of two α particles, one neutron, and one Ξ particle, and it is very unique because information about the interaction between spin-dependent Ξ -neutron can be obtained. Recently, Hiyama *et al.* pointed out that the phase shift S-wave Ξ -neutron interaction is sensitive to the theoretical models [1]. In the ESC model, triplet term is strongly attractive, while in the HAL-QCD, triplet term is weakly attractive. This difference might play an important role for the binding energy or level ordering of ${}_{\Xi}^{10}\text{Li}$. Hiyama *et al.* also calculated the binding energy and conversion energy of ${}_{\Xi}^{10}\text{Li}$ [2], but all calculated values of the conversion width vary from model to model, but all calculated results predict the existence of the bound state, and the binding energy is large enough to observe peak structures in the experiment using $S - 2S$ spectrometer.

To produce ${}_{\Xi}^{10}\text{Li}$, it is necessary to use the ${}^{10}\text{B}(K^-, K^+)X$ reaction with a boron-10 target. The momentum of K^- is analyzed with K1.8 beamline spectrometer. The resolution $\Delta p/p$ is 3.3×10^{-4} in FWHM. Scattered K^+ is analyzed through $S - 2S$ spectrometer with the resolution of 6.0×10^{-4} in FWHM. By using $S - 2S$ spectrometer, we can perform the missing mass spectroscopy with a very good mass resolution.

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The resolution of the missing mass can be written as:

$$\Delta M = \sqrt{\left(\frac{\partial M}{\partial p_{K^-}}\right)^2 \Delta p_{K^-}^2 + \left(\frac{\partial M}{\partial p_{K^+}}\right)^2 \Delta p_{K^+}^2 + \left(\frac{\partial M}{\partial \theta}\right)^2 \Delta \theta^2 + \Delta E_{target}^2} \quad (1)$$

Here, M is the missing mass, p_{K^-} (p_{K^+}) is the momentum of K^- (K^+), and θ scattering angle. This equation can be divided into two parts. The first three terms are derived from the performance of the spectrometer, which has a value of approximately 1.8 MeV in FWHM for $S - 2S$. To achieve a resolution of less than 3 MeV in FWHM in total, the last term, which originates from energy fluctuations inside the target, must be less than 2.5 MeV in FWHM.

Figure 1 shows the energy loss of K^+ mesons inside the boron target for different thickness. If the target thickness of 40 mm is selected, the energy fluctuation is estimated to be approximately 2 MeV in FWHM. To use a target of this thickness, the mean energy loss must be corrected by the Bethe-Bloch formula. To calculate the mean energy loss, it is necessary to reconstruct the vertices of the reaction with a resolution of about 1 mm.

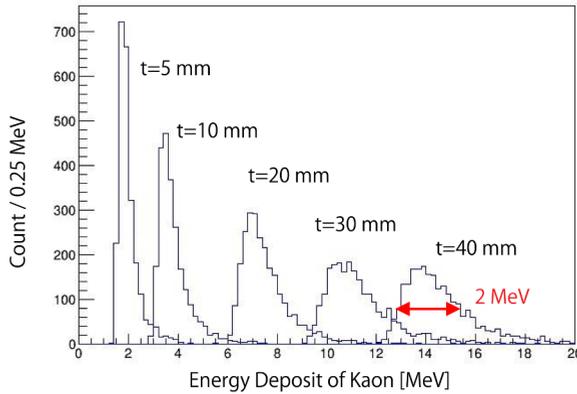


Figure 1. Energy loss of K^+ inside the target for different thickness

2 Experimental setup

Figure 2 shows a conceptual setup near the target system. From the right side of the figure, K^- beam is injected to the segmented boron target. A ${}^{10}_{\Xi}\text{Li}$, the Ξ -hypernucleus is produced inside the target associated with the scattered K^+ going to the left side. The boron target is segmented and tracking devices are placed around it. Single-sided Silicon Detectors (SSDs) or Double-sided Silicon Detectors (DSSDs) are used for the tracking devices, and scintillation counters are used to identify particle species. Pions from the decay of hypernuclei are detected by this system and used to reconstruct the vertex position, and the segment of the target where the event occurred is identified. Then, the calculated energy loss by Bethe-Bloch formula are used to correct the momentum for the K^- and K^+ . The vertex resolution of K^-/π and pion is estimated to be less than 1 mm.

The acceptance of this system is evaluated via a simple assumption that Ξ -N pair inside ${}^{10}_{\Xi}\text{Li}$ is converted to two Λ 's, which decay into neutron and π^0 or proton and π^- . The Q-value

of this decay is 28 MeV. Here, the momentum of Ξ -N is calculated from the ratio of the mass of Ξ -N to the total mass. In this assumption, vertex reconstruction efficiency is estimated to be approximately 30%. However, in real situations, $^{10}_{\Xi}\text{Li}$ has many decay modes such as twin hypernuclei, single hypernuclei and free Λ , etc. A detailed feasibility study of this method is currently underway using a more realistic assumption.

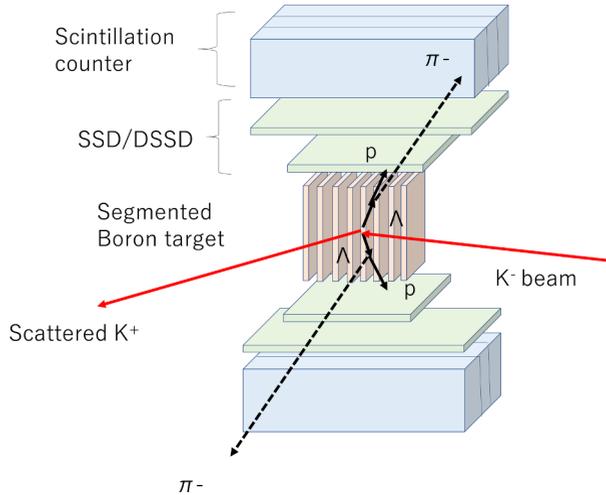


Figure 2. Conceptual experimental setup near the target system. The target is segmented to identify the reaction position. SSDs or DSSDs are installed to detect the decay particle. The scintillation counters are used to the identification of the particles.

3 Summary

We are planning to conduct a $^{10}_{\Xi}\text{Li}$ production experiments using boron targets at J-PARC, K1.8 beamline. This Ξ -hypernucleus is very important for obtaining a spin-dependent interaction between Ξ and neutron. A missing mass spectroscopy will be performed by using $S - 2S$ spectrometer. In order to achieve high yield and high resolution at the same time, we will prepare the target as thick as possible, and in addition, we will prepare a tracking system around the target. A resolution of 3.5 MeV missing mass can be achieved with a 40 mm thick target. Under simple assumptions, we expect to achieve about 30% acceptability with this system, but a more detailed validation check is needed.

References

- [1] E. Hiyama *et al.*, Phys. Rev. C **78**, 054316 (2008)
- [2] E. Hiyama *et al.*, Phys. Rev. Lett. **124**, 092501 (2020)