

## Comparison of ${}^3_{\Lambda}\text{H}/{}^4_{\Lambda}\text{H}$ production cross-section via $(K^-, \pi^0)$ reaction at J-PARC

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### Abstract.

Recent heavy-ion collision experiments reported a surprisingly short lifetime for the hypertriton, which has been recognized as the hypertriton lifetime puzzle. Our J-PARC E73 experiment contributes to solve this puzzle with an independent experimental method by employing  ${}^3\text{He}(K^-, \pi^0){}_{\Lambda}^3\text{H}$  reaction. In this contribution, we will demonstrate our capability to provide  ${}_{\Lambda}^3\text{H}$  binding energy information by deriving the production cross section ratio,  $\sigma_{\Lambda^3\text{H}}/\sigma_{\Lambda^4\text{H}}$ . The production cross section data for  ${}_{\Lambda}^3\text{H}$  and  ${}_{\Lambda}^4\text{H}$  are already available as the pilot run of E73 experiment and data analysis is in progress.

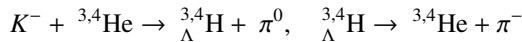
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## 1 Introduction

The hypertriton( ${}^3_{\Lambda}\text{H}$ ) is the lightest hypernucleus consisting of a proton, a neutron, and a  $\Lambda$  hyperon. Its properties, such as lifetime and binding energy, provide important benchmarks for hypernuclear physics. The  ${}^3_{\Lambda}\text{H}$  binding energy was measured to be  $0.13 \pm 0.05$  MeV[1] by the old emulsion experiment so that  ${}^3_{\Lambda}\text{H}$  has been considered to be a loosely bound system of  $\Lambda$  hyperon and deuteron for a long time. As a very loosely bound system, the  ${}^3_{\Lambda}\text{H}$  is expected to possess a similar lifetime as the free  $\Lambda$  hyperon ( $\tau = 263$  ps). However, there is inconsistency between the lifetime of  ${}^3_{\Lambda}\text{H}$  in heavy-ion collision experiments [2–4], which has been called the "hypertriton lifetime puzzle". Measured  ${}^3_{\Lambda}\text{H}$  lifetime is close to the free  $\Lambda$  hyperon with the reporting of very recent heavy-ion collision experiments[5, 6]. In contrast, a value of the binding energy of  ${}^3_{\Lambda}\text{H}$  has not yet been determined. Recently, a value of the binding energy of  ${}^3_{\Lambda}\text{H}$  of  $0.41 \pm 0.12$  MeV was reported by the STAR Collaboration[7], which was three times larger than the previous known value from emulsion data. On the other hand, preliminary value presented by the ALICE Collaboration confirms that the binding energy is small,  $0.05 \pm 0.06$  MeV[8]. Therefore, new data by using other methods on both lifetime and binding energy are needed.

## 2 J-PARC E73 experiment

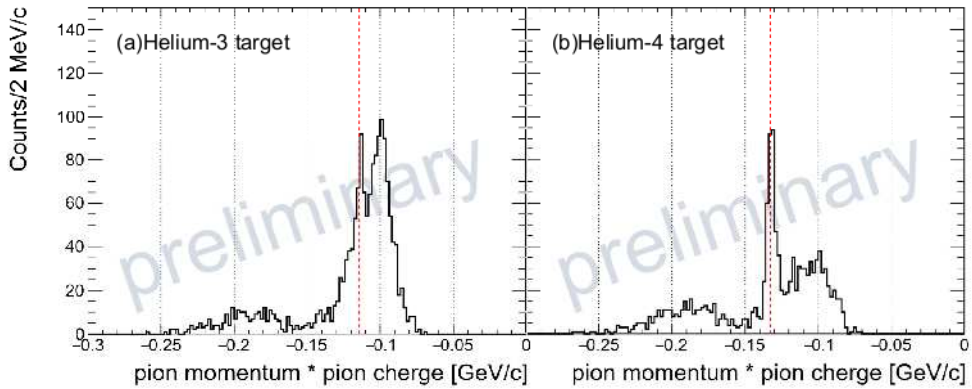
The J-PARC E73 experiment aims to pin down the "hypertriton lifetime puzzle"[9]. The lifetime will be obtained from direct measurement in the time domain so that the result is complementary to that from the heavy-ion collision experiments, in which the lifetime is extracted from an indirect measurement for the decay length. The E73 experiment employs the  $(K^-, \pi^0)$  reaction to populate  ${}^3_{\Lambda}\text{H}$  and  ${}^4_{\Lambda}\text{H}$  as:



This reaction is a novel production method to convert a proton into  $\Lambda$  hyperon. It is tagged by detecting gamma-ray from  $\pi^0$  meson with a forward calorimeter [10]. The hypernucleus produced in this strangeness exchange reaction is mainly in the ground state. The decayed  $\pi^-$  from the hypernucleus is measured by a cylindrical detector system (CDS) covering the target developed for an experiment to search for kaonic nuclei[11]. The CDS is composed of a solenoid magnet, a drift chamber and timing counters. In the  $(K^-, \pi^0)$  reaction at  $p_{K^-} = 1.0$  GeV/c, recent theoretical work reported that the information on  ${}^3_{\Lambda}\text{H}$  binding energy can be extracted from the production cross-section ratio  ${}^3_{\Lambda}\text{H}/{}^4_{\Lambda}\text{H}$ [12]. We can obtain production data with the same experimental setup, just by swapping targets.

## 3 Preliminary result

We have measured the  ${}^3_{\Lambda}\text{H}$  and  ${}^4_{\Lambda}\text{H}$  production as pilot experiments. The total beam times were 3 days at 51 kW beam power and 4.5 days at 60 kW beam power for the  ${}^3\text{He}$  and  ${}^4\text{He}$  targets, respectively. Since the hypernucleus decay at rest in our method, it can be identified by detecting the mono-energetic  $\pi^-$  from two-body mesonic weak decay. As shown in the fig.1, hypernuclear signals from two-body mesonic weak decay can be clearly seen. This is part of full data sample. The main background in this reaction is the quasi-free  $\Lambda$  and  $\Sigma$  in-flight decays. The background evaluation is underway using Geant4, taking into account Fermi motion and detector resolution. The number of hypernuclear signals is obtained by subtracting the simulated background from the data. We will compare the measured ratio to theoretical calculation and discuss the magnitude of the binding energy of  ${}^3_{\Lambda}\text{H}$ .



**Figure 1.** (a)The  $\pi^-$  momentum distribution in helium-3 target. Mono-energetic  $\pi^-$  from two-body mesonic weak decay signal is at 114 MeV/c. (b)The  $\pi^-$  momentum distribution in helium-4 target. Mono-energetic  $\pi^-$  from two-body mesonic weak decay signal is at 133 MeV/c.

## 4 Summary and outlook

The E73 experiment has obtained data with  $^3\text{He}$  and  $^4\text{He}$  targets to produce  $^3_\Lambda\text{H}$  and  $^4_\Lambda\text{H}$ , respectively. We presented the preliminary result of  $\pi^-$  momentum distribution in the ( $K^-$ ,  $\pi^0$ ) reaction. Mono-momentum  $\pi^-$  events have been clearly observed which come from two body decays of  $^3_\Lambda\text{H}$  and  $^4_\Lambda\text{H}$ . Finalization of the evaluation of the number of hypernuclear signals and systematic error are in progress. We will provide data on binding energy of  $^3_\Lambda\text{H}$  by using the ratio of the production cross-sections  $^3_\Lambda\text{H}$  and  $^4_\Lambda\text{H}$ .

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