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

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HYP 2022 PRAGUE

We have measured the $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H production using strangeness exchange reaction, ^{3}He, ^{4}He(K^-, π^0)$^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H, as J-PARC E73 experiment at the J-PARC K1.8BR beamline in Japan. The E73 experiment can provide important information for the $^{3}_{\Lambda}$H binding energy. A recent theoretical calculation suggests that the production cross-section ratio($^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H) can be used to study the binding energy of the $^{3}_{\Lambda}$H. We will introduce our preliminary result with this new method.

1. Introduction

- Although $^{3}_{\Lambda}$H is the lightest hypernucleus, its binding energy has not been determined yet. Recently, theoretical calculation[1] suggests that the production cross-section of $^{3}_{\Lambda}$H is strongly related to the binding energy, because of a loosely binding nature of $^{3}_{\Lambda}$H**.** In particular, the production cross-section ratio $^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H (R) with the same experimental setup can be discussed the $^{3}_{\Lambda}$H binding energy.

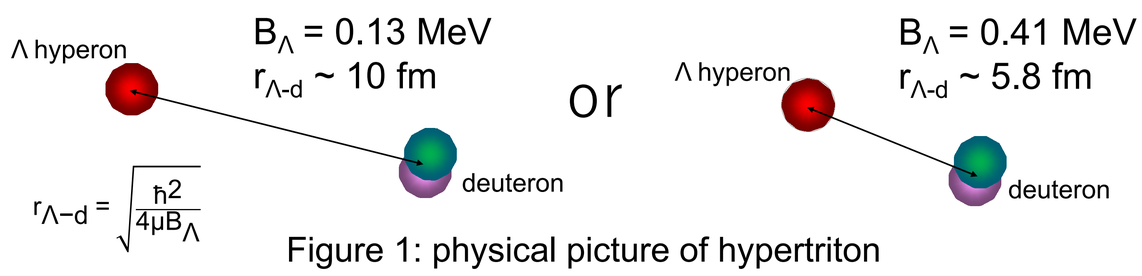


Figure 1: physical picture of hypertriton

- ✓ We will provide the information of binding energy of $^{3}_{\Lambda}$H and study the mechanism of the production and structure of $^{3}_{\Lambda}$H.

[1] T. Harada, Y. Hirabayashi, Nucl. Phys. A 1015(2021)122301.

2. J-PARC E73 experiment

- J-PARC E73 experiment employs the (K^-, π^0) reaction. This is a novel production method to convert a proton into Λ hyperon by tagged by π^0 meson. Hypernucleus of the ground state is selectively produced by this so-called strangeness exchange reaction.

$K^- + {}^{3}\text{He}, {}^{4}\text{He} \rightarrow {}^{3}_{\Lambda}\text{H}, {}^{4}_{\Lambda}\text{H} + \pi^0$ (tag)

${}^{3}_{\Lambda}\text{H}, {}^{4}_{\Lambda}\text{H} \rightarrow {}^{3}\text{He}, {}^{4}\text{He} + \pi^-$ (measure)

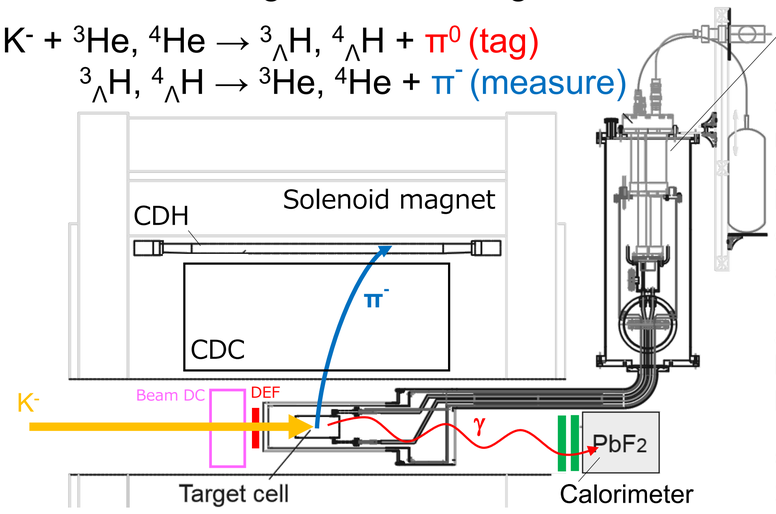


Figure 2: Overview of the setup in K1.8 BR Beamline

CDS is composed of a solenoid magnet, a drift chamber and timing counters.
Momentum resolution ~ 2.4 MeV/c

We use the PbF_2 crystal, a Cherenkov light-based calorimeter. The energy resolution is σ/E ~ 5 % at 1 GeV and the PbF2 crystals have a nice separation between pion and electron.

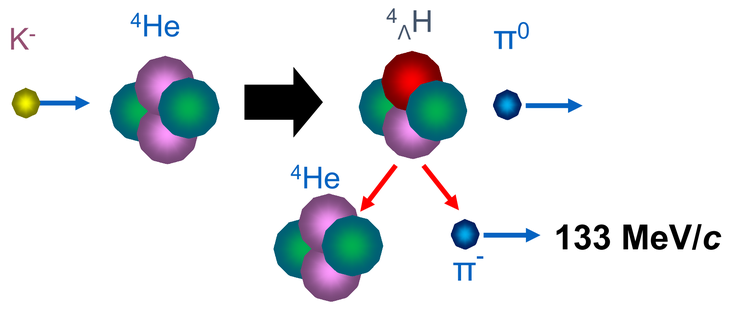
cf. Dr. Y. Ma's talk in Session 1; Mon-Ⅱ

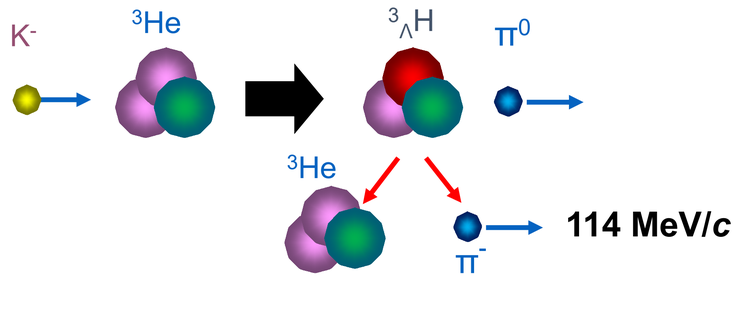
3. Analysis Result

- The π^- momentum distribution can be obtained from CDS. As shown in the figure 3 and figure 4, π^- signal from hypernuclear mesonic weak decay can be clearly seen. This is the first successful identification of hypernucleus by tagged by π^0 without using the missing-mass method. The background events from quasi-free Λ and Σ in-flight decay are well reproduced by geant4 simulation.

Table 1: Beam time summary

Target	^{4}He(0.144 g/cm^3)	^{3}He(0.070 g/cm^3)
Date	June 2020	May 2021
BeamTime	65 hours (~ 3 days)	107 hours (~ 4.5 days)
# of Beam	5.0 G Kaon	8.8 G Kaon





The high momentum π^0 is used to tag Λ hyperon productions with smaller recoiling momentum, which has higher formation probability of hypertriton.

Since the hypernucleus decay at rest, the hypernucleus can be identified by finding a mono-momentum π^-.

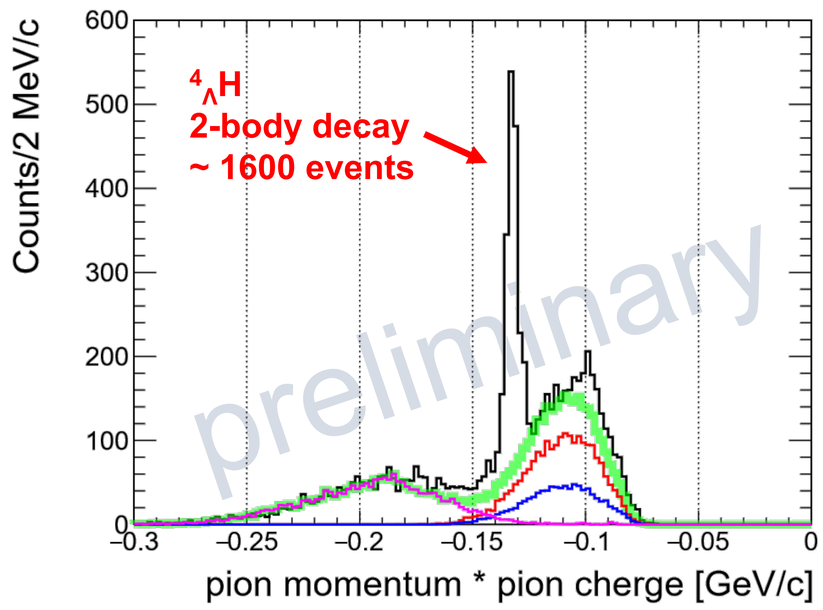


Figure 3: π^- momentum distribution of ^{4}He target

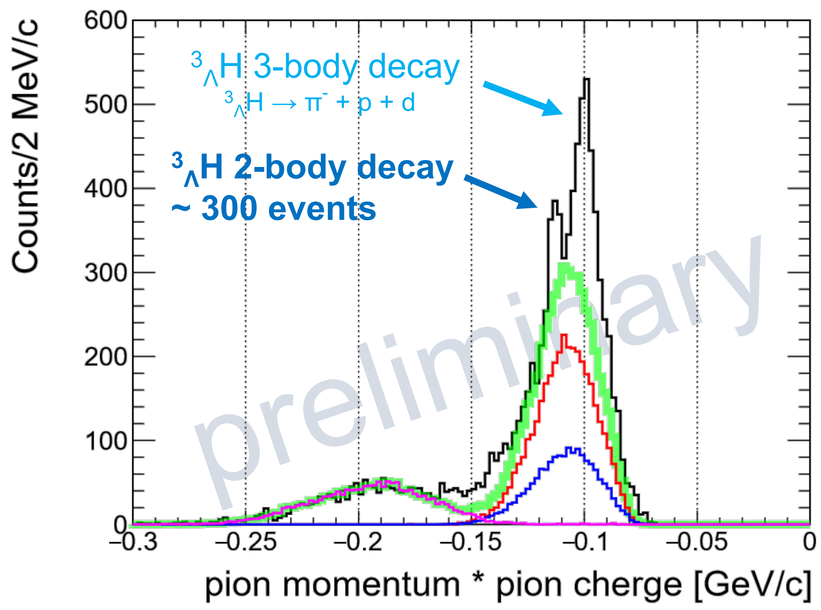


Figure 4: π^- momentum distribution of ^{3}He target

– Data
– QF-Λ (Sim)
– QF-Σ^0 (Sim)
– QF-Σ^- (Sim)
– All(Sim)

In order to enhance the hypernucleus signal to noise ratio, calorimeter energy selection and Distance of closest approach(DCA) cut were performed in the offline analysis.

The geant4 simulation is implemented with realistic geometry, Fermi motion, and detector resolution.

3-body decay of hypertriton were also observable[2].

[2] H. Kamada et al., Phys. Rev. C 57(1998)1595

4. Discussion

- The number of hypernuclear signals is obtained by subtracting the simulated background from the data. Since acceptance and efficiency are almost the same, the ratio of the hypernuclear yield after correcting the branching ratio is directly the ratio of the cross-section. Our preliminary result shows R ~ 0.4. This suggests that a shallow bound $^{3}_{\Lambda}$H consistent with emulsion data.

cf. B_Λ=0.13 MeV(Emulsion) ⇒ R ~ 0.3–0.4
B_Λ=0.41 MeV(STAR) ⇒ R ~ 0.65

Table 2: the number of hypernuclear signals

Hypernucleus	$^{4}_{\Lambda}$H	$^{3}_{\Lambda}$H	$^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H
# of signal	1.6×10^3	3×10^2	0.20
Branching ratio	50 %	25 %	0.50
Luminosity(L)	1.1 $(nb)^{-1}$	1.2 $(nb)^{-1}$	1.1
# of signal/(BR*L)	2.9×10^3	1.1×10^3	**~0.4**

5. Summary and Outlook

- The E73 experiment has already been performed with ^{4}He, and ^{3}He targets to produce $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H, respectively. We showed the preliminary result of π^- momentum distribution in the (K^-, π^0) reaction.
  - ✓ Mono-momentum π^- events are clearly observed which come from two body decay of $^{4}_{\Lambda}$H and $^{3}_{\Lambda}$H.
- Ratio of production cross-section $^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H is suggested a sensitive observable for the binding energy of $^{3}_{\Lambda}$H.
  - ✓ A rough estimation of the cross-section ratio, $^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H , has been obtained, which is evaluated to be R ~ 0.4.
  - ✓ Obtained R-value suggests that $^{3}_{\Lambda}$H is a loosely bound system.
- Finalization of the number of hypernuclear signals and evaluation of systematic error are in progress.