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The Third Generation (e, e′K⁺) Λ Hypernuclear Spectroscopy at JLab*

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Abstract: We are now preparing for the third generation (e, e′ K⁺) Λ hypernuclear spectroscopic experiment at Hall C, Jefferson Lab (USA). The goal of the experiment is the precise spectroscopy of hypernuclei in wide mass region. We have constructed a new high resolution electron spectrometer "HES" dedicated to (e, e′ K⁺) hypernuclear study in Japan and it was shipped to JLab in February, 2008. We will discuss about the physics of the (e, e′ K⁺) hypernuclear study at JLab and report the current preparation status of the third generatrion experiment.

Key words: hypernuclei; JLab; HES; HKS

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1 Introduction

Hypernuclei is one of the important tool to investigate deeply the inside of nuclei utilizing new degree of freedom, strangeness[1-4]. The knowledge of nuclear structure and hyperon-baryon (Y-N) interaction is important for many subjects, for example, the understanding of internal of neutron star.

In order to investigate deeply the inside of nuclei, traditional experimental techniques such as (e, e′p) or (p, 2p) is not enough. Because the nuclear deeply bound state get broader (~5 MeV for the 1-f shell proton states of ^{208}Pb) and therefore precise spectroscopic investigation is prohibited. However, in hypernuclear case, the width of deeply bound states is up to a few hundred keV, beacuse Y-N interaction is weaker than N-N inter-

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action.

We can study Y-N interaction well from hypernuclear spectroscopic investigation. Basically, this kind of study should be performed through hyperon-nucleaon scattering experiment. However, such a experiment is quite difficult to be carried out beacuse hyperon lifetime is quite short (of the order of 10^{-10} s). Information from spectroscopic study of hypernuclei is very valuable for understanding Y-N interaction.

Spectroscopic study of Λ hypernuclei started in 1970s at CERN using (K^-, π^-) reaction[5—12] (Table 1). Since beam energy and intensity was limited at that time, statistics was poor and only ground states were studied. However, it is important that this method establish hypernuclear spectroscopic experiment. The (K^-, π^-) reaction will be used with very high intensity kaon beam in future J-PARC experiment.

In 1980s, (π^+, K^+) reaction spectroscopy was starting at BNL-AGS[13, 14]. Since (π^+, K^+) reaction has large momentum transfer compared to (K^-, π^-) reaction (~400 MeV/c at p_π ~1.0 GeV/c), Furthermore, in 1990s, spectroscopic study using high resolution spectrometer (SKS), started in KEK-12 GeV PS[5—19]. The mass resolution was as good as 2 MeV. This study provides us systematic information about hypernuclei up to $^{208}_{\Lambda}$Pb.

Finally in 2000, our group carried out the first generation (e, e′K^+) hypernuclear spectrospcopic experiment at Hall-C, Jefferson Lab, USA[20, 21]. The (e, e′K^+) reaction (Fig. 1) converts proton to Λ therefore we can generate neutron-rich hypernuclei compeared to (K^-, π^-) and (π^+, K^+) reactions which convert neutron to Λ. This reaction has also enough momentum transfer to excite deeply bound states which is almost same as (π^+, K^+) reaction. In the first generation experiment, we achieved sub-MeV energy resolution and proved a principle that (e, e′K^+) Λ hypernuclear spectroscopy is possible.

Table 1 Reactions used for the hypernuclear spectroscopy

	(K^-, π^-)	(π^+, K^+)	(e, e′K^+)
Reaction type	n to Λ	n to Λ	p to Λ
Facility	1970s-, CERN, BNL	1980s-, BNL, KEK	2000s-, JLab
Mom. transfer	<0.2 GeV/c	>0.4 GeV/c	>0.4 GeV/c
	(p_K=0.8 GeV/c)	p_π=1.0 GeV/c	p_e=2.0 GeV/c

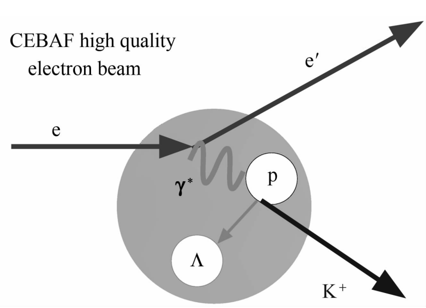

Fig. 1 Figure of (e, e′K^+) reaction.

2 Physics Motivation

We perfomed (e, e′K^+) Λ hypernuclear spectroscopic experiments in twice, namely, the first experiment in 2000 and the second experiment 2005[22]. We performed $^{12}_{\Lambda}$B spectroscopy in the first experiment and $^{7}_{\Lambda}$He, $^{12}_{\Lambda}$B and $^{28}_{\Lambda}$Al spectroscopy in 2nd experiment.

Our next motivation is to perform pricise Λ hypernuclear spectroscopy in wider mass region[23]. We constructed new spectrometer (HES) for electron arm in order to achieve this purpose (see section 3). We are now planning to carry out the spectroscopy of $^{7}_{\Lambda}$He, $^{10}_{\Lambda}$Be, $^{40}_{\Lambda}$K and $^{52}_{\Lambda}$V.

For $^{7}_{\Lambda}$He and $^{10}_{\Lambda}$Be, recent theoretical approach especially using cluster model has been making progress and we intend to compare pricise experimental data with these works. One of the hot topics in this region is Charge Symmetry Breaking (CSB). According to cluster model calculation by Hiyama et al., ground states of $A=7$ isotriplet, namely, ${}^{7}_{\Lambda}\mathrm{He}=\alpha+\Lambda+n+n$, ${}^{7}_{\Lambda}\mathrm{Li}=\alpha+\Lambda+n+p$ and ${}^{7}_{\Lambda}\mathrm{Be}=\alpha+\Lambda+p+p$ have different binding energy each even after coulomb energy correction[24]. This may be an indicator of CSB of the strong interaction. Especially for ${}^{7}_{\Lambda}\mathrm{He}$, there exists only poor statistics data for the emulsion experiment and higher quality data for us is longed. Similar study is possible for $A=10$ isotriplet.

For ${}^{40}_{\Lambda}\mathrm{K}$ and ${}^{52}_{\Lambda}\mathrm{V}$, one of the significant motivation is to measure the A dependence of the Λ single particle energies. Fig. 2 shows the A dependence of Λ single particle energies calculated by mean-field theories with various parameters. For example, in order to study $A\rightarrow\infty$ limit, precise experimental input from the light to medium heavy hypernuclei is quite important for such kind of study.

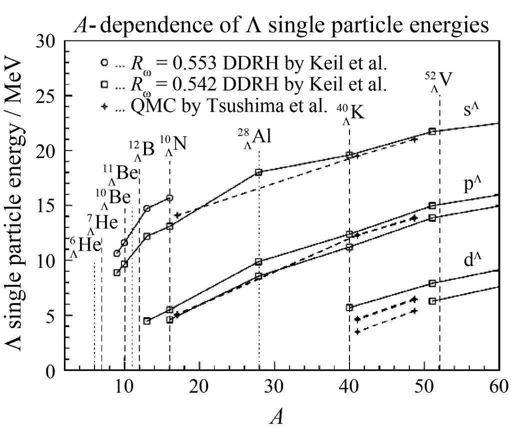

Fig. 2 The calculated A dependence of Λ single particle energies of s^{Λ}, p^{Λ}, d^{Λ} states for various hypernuclei[25, 26].

The experiment is expected to provide important insight of Y-N interaction. The effect of ΛN-ΣN coupling can be well studied by precise light Λ hypernuclei data. The heavier Λ hypernuclei will provide the information about spin-orbit splitting and core nucleus configuration.

3 Experimental Setup Prearation Status

In the second experimet, we made mainly two improvement, one is the construction of new spectrometer in Kaon arm (HKS) in order to achieve better energy resolution. Another improvement is making electron arm spectrometer a tilt to avoid background events in electrom arm which is mainly come from bremsstrahlung and møller scattering process(tilt method, detail will be given in later). These improvement worked fine, but mismatch between HKS and existing electron spectrometers reduced hypernuclear yield. It is estimated to improve hypernuclear yield and signal-to-noise ratio for heavier hypernuclear study.

Therefore, we constructed new Q-Q-D type spectrometer in electron arm, named HES, which has larger acceptance and higher resolution than previous one (see Table 2, Fig. 3).

Table 2 HKS and HES performance

	HKS	HES
Confuguration	Q-Q-D (70°)	Q-Q-D (50°)
Central momentum	1 200 MeV/c	844 MeV/c
Mom. acceptance	±17%	±12.5%
Solid Angle	~10 msr	~8 msr
Mom. resolution (FWHM)	2×10^{-4}	2×10^{-4}
Ang. resolution (FWHM)	2 mrad	3 mrad

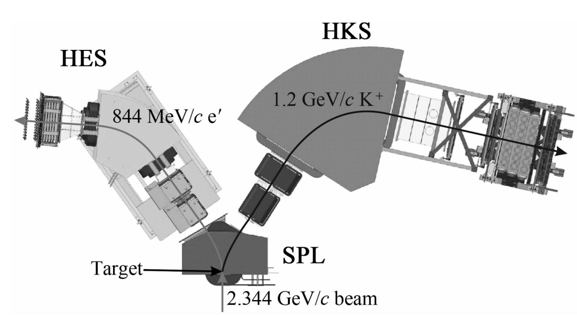

Fig. 3 Entire experimental setup for the 3rd experiment.

We constructed a new splitter magnet (SPL) and the role of it is to distinguish charged particle in forward angle. Target is placed in the vaccum chamber of SPL.

HES and SPL were constructed in Japan. Magnetic field measurement was carried out and the difference between calculated field (using TOSCA) is confirmed to be less than a few.

Tilt method　Our main background source in electron arm come from bremsstrahlung and Mϕller scattering processes. These background is concentrated on more forward than virtual photon (VP) associated events (see Fig. 4). Therefore, we avoid very forward acceptance by tiltig spectrometer vertically, and got better S/N ratio in the 2nd experiment. We can use stronger beam since the background rate get lower.

Detector R&D　For HKS side, we can use basically the same detectors as previous experiment (listed in Table 3). There are some background protons and pions in HKS side in the order of 10 kHz, therefore we have to reject these events more than 99% to make kaon trigger, TOF $\otimes \overline{AC} \otimes$ WC. We need to improve the performance of Water Cherencov (WC) counter for the next experiment since severer proton background is expected. We are now working on developing new WC and additional Lucite Cherencov counter.

For HES side, we use two drift chambers and two layers TOF counters. The two chambers are named EDC1 and EDC2, EDC1 is identical one as previous electrom arm drift chamber and EDC2 is the same type as KDCs. We are constructing new TOF layers. Each counters have been already tested in LNS in Tohoku University, achieving about 100 ps (sigma) intrinsic timing resolution which is balanced with HKS timing resolution.

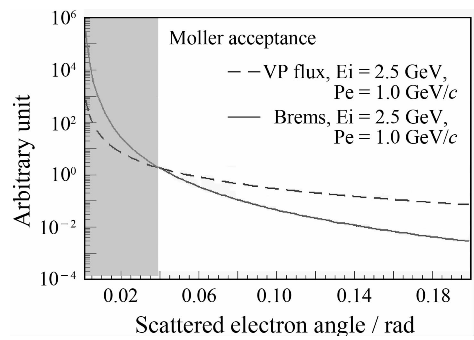

Fig. 4　The rate dependency on scattering angle of VP associated event (---) and bremsstrahlung associated event (—). Cian region shows the acceptance of Mϕler scattering.

Table 3　HKS-HES detectors

Detector name	Effective region	Comment
HKS		
KDC1, 2	$30^H \times 122^W \times 5^T$ cm^3	Drift chamber, u, u′, x, x′, v, v′
KTOF-1x	$30^H \times 125^W \times 2^T$ cm^3	TOF counter, 7.5^{W}cm ×17-segments
KTOF-1y	$32^H \times 125^W \times 2^T$ cm^3	TOF counter, 3.5^{H}cm ×9-segments
AC1, 2, 3	$46^H \times 169^W \times 31^T$ cm^3	Aerogel Cherencov for pion veto
WC1, 2	$35^H \times 180^W \times 7.5^T$ cm^3	Water Cherencov for proton veto, 7.5^W×12-segments
KTOF-2x	$35^H \times 170^W \times 2^T$ cm^3	TOF counter, 9.5^{W}cm ×18 -segments
LC1	$40^H \times 180^W \times 2^T$ cm^3	Lucite Cherencov for proton veto, 14^{W}cm ×13-segments
HES		
EDC1	$12^H \times 100^W \times 30^T$ cm^3	Honey comb cell type drift chamber, x, x′, u, u′, x, x′, v, v′, x, x′
EDC2	$30^H \times 122^W \times 5^T$ cm^3	Drift Chamber, copy of KDC, u, u′, x, x′, v, v′
ETOF-1, 2	$30^H \times 145^W \times 1^T$ cm^3	TOF counter, 5.0^{W}cm ×29-segments

Yield estimation, energy resolution　As a result of constructing HES, scattered electron yield is expected to be roughly 8 times larger than that of the previous experiment. However, since we constructed larger SPL, the effective solid angle of HKS is about 60% of the previous one. Finally, we estimated to get about 5 times larger yield than previous experiment (Table 4).

Table 4 Yield estimation for the 3rd experiment and comparation to the 2nd experiment

Target (100 mg/cm^2)	the 2nd expriment (1.854 GeV beam)	the 3rd experiment (2.344 GeV beam)
^{7}Li	8.5	34
^{10}B	9.6	47
^{12}C	9.6	39
^{40}Ca	—	12
^{52}Cr	—	9

Since the momentum resolution of the beam is less than 10^{-4}, estimated total energy resolution is expected to be less than 400 keV (Table 5). Totally, beam, HKS and HES momentum resolutions contribute to the mass resolution equally and the contribution from angular resolution and target enegy is negligible in all target (thickness is assumed to be 100 mg/cm^2).

Table 5 Contributions to the mass resolution. The resolutions of HKS and HES is listed in Table 2 and beam resolution is 7×10^{-5}. Target thickness is assumed to be 100 mg/cm^2

Item	Contribution (keV, FWHM)			
Target	^{7}Li	^{12}C	^{40}Ca	^{51}V
HKS momentum	210	210	220	220
HKS angle	40	20	10	10
HES momentum	280	280	290	290
HES angle	40	20	10	10
Beam momentum	160			
Target energy loss	100	100	100	80
Total	330	330	330	330

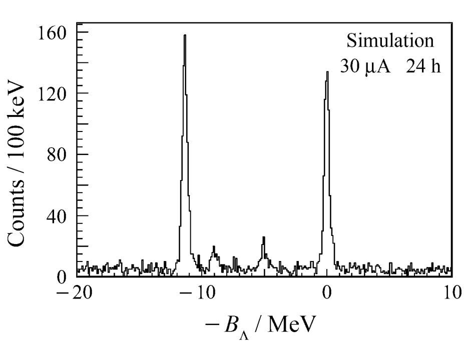

Fig. 5 The expected $^{12}_{\Lambda}$B spectra in 24 h.

Fig. 5 shows expected $^{12}_{\Lambda}$B spactra. This figure does not contain the quasi-free event, but contain the background events come from bremsstrahlung. Although the background event rate is almost same as previous experiment, signal event rate get 5 times larger. Therefore we can ahieve much better S/N ratio than last experiment and the hypernuclear spectroscopy in heavier target becomes feasible.

4 Summary

We are now preparing for the third generation (e, e′K$^+$) hypernuclear spectroscopy at JLab Hall-C and the experiment will be ready for beam summer 2009. The physics motivation of the experiment is to carry out hypernulcear spectroscopy in wide mass region, from A=7 to A=52.

For this purpose, we constructed the larger acceptance and high resolution electron spectrometer, HES. As a result, it is expected that we can achieve 5 times larger hypernuclear yield than the last experiment and better than 400 keV (FWHM) mass resolution.

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