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Hypernuclear spectroscopy program at JLab Hall C

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Abstract

Hypernuclear production by the $(e, e'K^+)$ reaction has unique advantages in hypernuclear spectroscopy of the $S = -1$ regime. The second-generation spectroscopy experiment on ^{12}C, ^{7}Li and ^{28}Si targets has been recently carried out at JLab Hall C with a new experimental configuration (Tilt method) and also using a new high-resolution kaon spectrometer (HKS). The experiment is described and preliminary results are presented together with the empasis of significance of the $(e, e'K^+)$ reaction for Λ hypernuclear spectroscopy and its future prospects.

PACS: 21.80.+a; 21.10.Dr; 21.60.Cs

1. Introduction

A Λ hyperon, being free from the Pauli exclusion principle from nucleons, is a unique probe that senses interior of hadronic many-body systems. Mean field aspects of nuclei can be well investigated using a Λ hyperon as a probe. At the same time, hyperon–nucleon interactions can be studied quantitatively through the structure information of hypernuclei. In recent years, hypernuclear investigation made rapid and fruitful progress thanks to advanced state-of-art experiments. It became now possible to experimentally study hadronic many-body systems having strangeness with high-quality data to which we did not have access previously. In particular, spectroscopic experiments play an indispensable role in the investigation of Λ hypernuclei [1,2].

Until very recently, Λ hypernuclear spectroscopy experiments have been carried out using meson-induced (K^-, π^-) and (π^+, K^+) reactions. These experiments were conducted mostly at the high-energy proton synchrotron facilities such as KEK 12 GeV PS and BNL AGS, where intense meson beams suitable for hypernuclear spectroscopy were delivered.

In addition to the meson-induced reactions, it has been known for some time that electroproduction of strangeness offers unique opportunity for the investigation of "strange" hadronic many-body systems, particularly $S = -1$ system [3–5]. The $(e, e'K^+)$ reaction has valuable advantages for hypernuclear spectroscopy which are not realized in the meson-induced reactions but complementary to those reactions, even though the experiments are difficult. The characteristics relevant to Λ hypernuclear spectroscopy are as follows,

- A proton in the target is converted to a Lambda hyperon, in contrast to the (π^+, K^+) and (K^-, π^-) reactions which convert a neutron to a Lambda. Therefore, the range of hypernuclei to be studied spectroscopically can be greatly extended using the $(e, e'K^+)$ reaction. Particularly in the light mass region, neutron-rich Λ hypernuclei can be produced. Compar-

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ison of the hypernuclear spectra by the $(e, e'K^+)$ reaction with those by the (K^-, π^-) and (π^+, K^+) reaction allows us to study charge symmetry in Λ hypernuclei.

- A large momentum ($\sim$ 320 MeV/c at 0 degrees) is transferred to a recoil hypernucleus similarly to the (π^+, K^+) reaction. It thus populates high-spin states and is suitable to investigate deeply bound states of a Λ hyperon.
- Sizable spin-flip amplitudes are present in the elementary process even at 0 degrees. Such feature persists in the hypernuclear production and thus both spin flip and spin non-flip hypernuclear states are excited with comparable cross sections.
- From the experimental point of view, the $(e, e'K^+)$ reaction has a potential power that makes hypernuclear reaction spectroscopy with sub-MeV mass resolution possible. A few 100 keV resolution, which is comparable to expected spreading widths of hypernuclear states even when they are excited above the nucleon emission thresholds, can be realized. Such high resolution spectroscopy becomes possible only when high-quality primary electron beams are available.
- Small and thin targets, and, therefore, even enriched isotope targets, can be used because the beam spot size at the target is as small as $\varnothing$ 0.1 mm thanks to the high-quality primary beam. It is in contrast to the meson induced reactions that require thick and large targets to have enough hypernuclear yield rates.

In Fig. 1, hypernuclear excitation spectra which we expect to observe by the three reactions, (K^-, π^-), (π^+, K^+) and $(e, e'K^+)$, are compared, demonstrating characteristic features of each reaction. It is seen the $(e, e'K^+)$ reaction will be a suitable tool for hypernuclear spectroscopy if high resolution can be achieved. At JLab, there have been two parallel experimental efforts for hypernuclear spectroscopy in Hall A and C. This paper focuses on the recent progress of the Hall C hypernuclear program [6,7]. A recent update of the status of Hall A experiment is presented in Refs. [8,9].

2. Hypernuclear spectroscopy by electron beams

Hypernuclear spectroscopy by the $(e, e'K^+)$ reaction requires a high quality GeV electron beam in order to produce "strangeness". It also needs 100% duty factor since it is necessary to detect a kaon and a scattered electron in coincidence. Even at present, electron beams that satisfy these requirements for hypernuclear spectroscopy are available only at CEBAF (Continuous Electron Beam Accelerator Facility) of Thomas Jefferson National Accelerator Facility at Virginia (JLab).

Basic kinematics of the $(e, e'K^+)$ reaction adopted in the Hall C experiments is illustrated in Fig. 2. The electron beams at 1.7–1.8 GeV bombard a target. Scattered electrons of 0.3 GeV/c and kaons of 1.2 GeV/c are measured in high background environment associated with high intensity electron beams. Two spectrometers, one the scattered electron spectrometer and the other the kaon spectrometer, accept electrons and kaons, and momentum-analyze their trajectories. In the hall C configuration, a splitter magnet is installed immediately downstream of the target in order to measure electrons and kaons at very forward angles. Scattered electrons and positive kaons at very forward angles are deflected to the opposite directions and guided to each spectrometer.

The first successful experiment was carried out using the HyperNuclear Spectrometer System (HNSS) in Hall C as JLab E89-009 in 2000 [10,11]. The experiment was designed to take the "0 degree tagging" configuration, in which the 0-degree electrons associated with the most in-

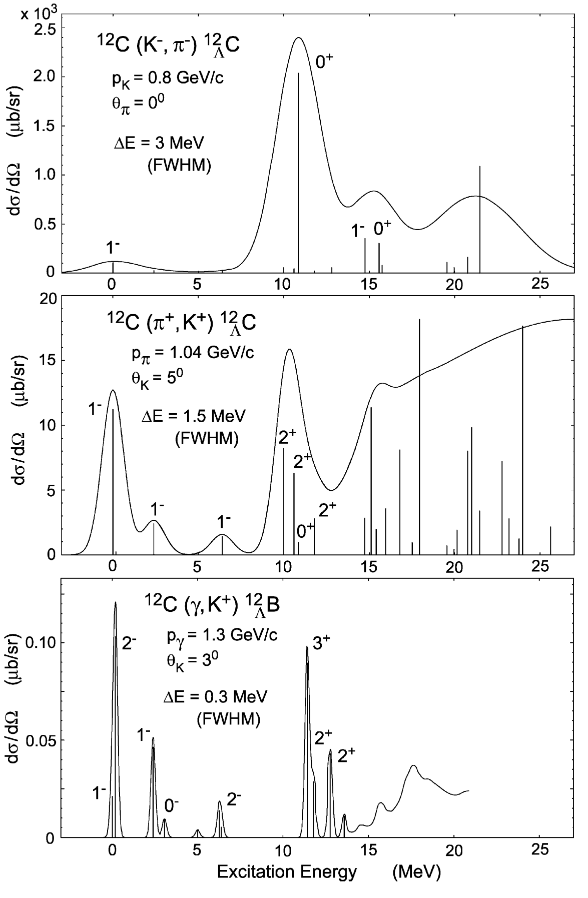

Fig. 1. Comparison of the excitation functions to be observed in the (K^-, π^-), (π^+, K^+), and $(e, e'K^+)$ reactions on a ^{12}C target.

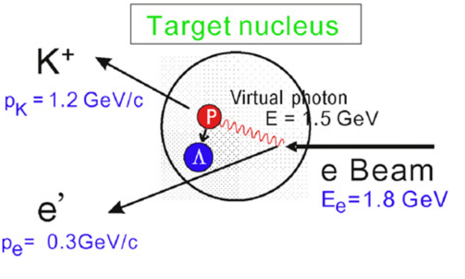

Fig. 2. Typical kinematics of the $(e, e'K^+)$ reaction adopted in the Hall C hypernuclear experiments.

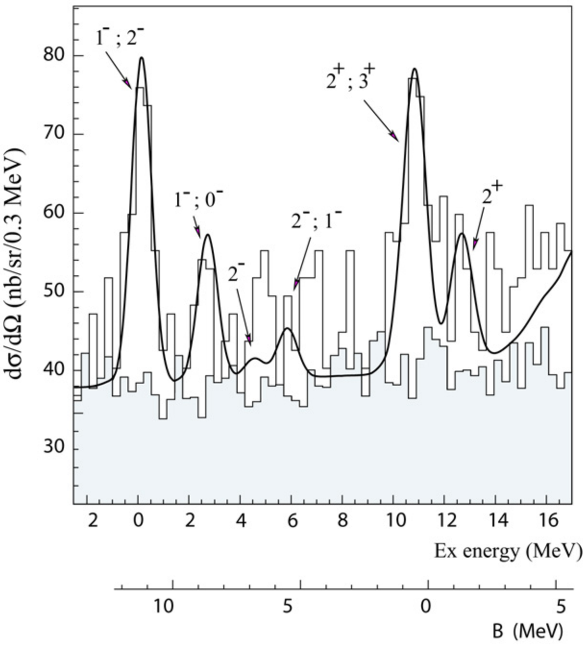

Fig. 3. Missing mass spectrum of $^{12}C/CH_x(e, e'K^+)$ reaction. The shaded histogram is the accidental background, which was experimentally derived [10].

tense virtual photons were detected. The old split-pole type spectrometer designed by Prof. Enge was used as the scattered electron spectrometer. Kaons were measured by the Short Orbit Spectrometer (SOS), which is standard in Hall C, and have a wide momentum acceptance of $\pm 12.5\%$ in the 1 GeV/c region and a reasonably good momentum resolution of 5×10^{-4}.

Sub-MeV resolution, which was the best resolution achieved in the reaction spectroscopy as of spring of 2004, was demonstrated in the experiment by the $^{12}C(e, e'K^+)^{12}_{\Lambda}B$ reaction [10]. In Fig. 3 is shown a missing mass spectrum. The horizontal axis is given in units of excitation energy and also Λ binding energy, B_Λ, assuming the ^{11}B core nucleus is in its ground state. The energy resolution was evaluated by the width of the ground state peak to be 0.75 MeV (FWHM), which was considerably better than the best one (1.45 MeV) obtained in the (π^+, K^+) reaction using the SKS spectrometer at KEK 12 GeV PS. Both of the s_Λ and p_Λ doublets, $(1^-, 2^-)$ and $(2^+, 3^+)$, were not resolved. It was believed that the splitting is smaller than a few tens of keV.

3. The second generation $(e, e'K^+)$ hypernuclear spectroscopy at JLab Hall C

Although the first $(e, e'K^+)$ experiment, E89-009, was successfully carried out and it was proved that a sub-MeV resolution was achievable, there still remained further challenges which should be overcome before Λ hypernuclear spectroscopy was fully explored taking the advantages of the $(e, e'K^+)$ reaction.

Firstly, hypernuclear yield rates were too low (0.9 counts/h for the ground state of $^{12}_{\Lambda}B$) and it took almost 1 month to obtain the $^{12}_{\Lambda}B$ spectrum. Since the scattered electrons were measured including 0 degrees, electrons associated with the Bremsstrahlung process entered the acceptance of the electron spectrometer. Therefore, we could carry out the data taking only

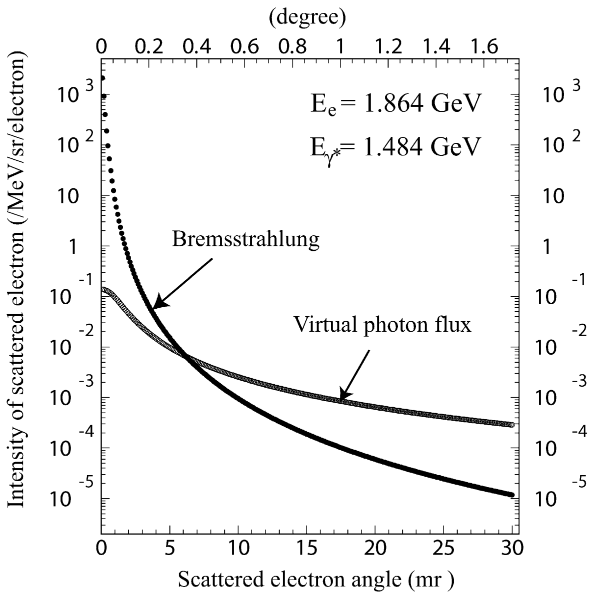

Fig. 4. Angular distributions of electrons associated with the bremsstrahlung process and virtual photons of Λ hypernuclear production.

with low luminosity, that is, with a low-intensity electron beam (0.6 μA) and a thin target (20 $\mathrm{mg/cm^2}$ $^{12}\mathrm{C}$). For the investigation of heavier Λ hypernuclei, background electrons become prohibitingly dominant and serious, since its rate is expected to be approximately proportional to Z^2. It is necessary to suppress the background electrons at very forward angles in order to conduct efficient spectroscopy experiments by the $(e, e'K^+)$ reaction.

Secondly, the hypernuclear mass resolution could not be further improved because the SOS spectrometer has only medium momentum resolution. In addition, kaon rates were limited partly due to the small acceptance of the kaon spectrometer.

Examing the E89-009 data, a new experimental configuration ("Tilt method") was proposed for the second generation experiment, JLab E01-011 [7]. In the proposed experiment, we intended to considerably increase hypernuclear yield rates compared with the E89-009 experiment. The tilt method is based on the fact that the angular distribution of the virtual-photon-associated electrons is less forward peaked compared to that of bremsstrahlung-associated electrons as shown in Fig. 4.

The electron spectrometer was positioned at very forward angles, guaranteeing higher rates of virtual photons as much as possible, but it was vertically tilted in order to suppress the background of electrons due to the electromagnetic processes such as Bremsstrahlung and Møller scattering.

In addition, the SOS spectrometer that was used for analyzing kaon momenta in the previous E89-009 was replaced by a new high-resolution kaon spectrometer (HKS). It was designed to have a momentum resolution as good as 2×10^{-4} and also 3 times higher geometrical acceptance compared with the SOS spectrometer.

The experimental parameters of the E01-011 experiment are compared with those of E89-009 in Table 1.

Table 1
Experimental condition and specification of the JLab E01-011 experiment

	E89-009	E01-011
Beam condition		
Beam energy	1.8 GeV	same
Beam momentum stability	1×10^{-4}	same
General configuration	Splitter + Kaon spectrometer + Electron spectrometer	same
Kaon spectrometer		
Spectrometer	SOS spectrometer	HKS spectrometer
Configuration	QDD (vertical bend)	QQD (horizontal bend)
Central momentum	1.2 GeV/c	1.2 GeV/c
Momentum acceptance	±10%	12.5%
Resolution ($\Delta p/p$)	5×10^{-4} (beam spot size 0.1 mm assumed)	2×10^{-4}
Solid angle (with splitter)	5 msr	20 msr
Solid angle (without splitter)	9 msr	30 msr
Kaon detection angle	0–7 degrees	1–14 degrees
Flight length	8 m	10 m
Scattered electron spectrometer		
Enge split-pole spectrometer		
Central momentum	0.3 GeV/c	same
Momentum acceptance	±20%	same
Momentum resolution ($\delta p/p$)	2×10^{-4}	same
Tilt angle (vertical)	0 degrees	8 degrees
Electron detection angle		
Horizontal	0 degrees	same
Vertical	< 2.25 degrees	3.7–5.7 degrees

The spectrometer system was installed in JLab hall C as shown in Fig. 5 and a schematic plan view of the E01-011 experimental setup is also presented in Fig. 6.

In the new configuration, scattered electrons and kaons are bent by a splitter magnet to the opposite directions with each other as in the case of the E89-009 experiment. However, the electron spectrometer is tilted by a small angle vertically, that is, perpendicular to the dispersive plane of the splitter magnet as shown in Fig. 7. The tilt angle was carefully optimized considering a realistic geometrical configuration. Angular distributions of bremsstrahlung electrons and Møller electrons are dependent on the beam energy, peaking more forwardly with the higher beam energy. For the E01-011 setup with 1.8 GeV beam energy, an angular distribution of the Møller electrons extends to the larger angles compared with that of bremsstrahlung electrons. Thus, it is necessary to set the acceptance of the electron spectrometer outside the Møller ring for a given momentum acceptance of the electron spectrometer. The optimized tilt angle depends on the experimental condition. In the E01-011 experiment, it was found to be 8 degrees, corresponding to the scattering angle of electrons as forward as 4.5 degrees. With this “tilted” configuration, an electron beam of 30 μA can be accepted even with a 100 mg/cm^2 ^{12}C target. Under such condition, the singles rate at the focal plane of the scattered electron spectrometer is kept as low as 1 MHz. It is 200 times less than the case of E89-009, even though the luminosity is more than 150 times brighter. Hadronic rates in the kaon spectrometer become much higher than those of E89-009 because of the higher luminosity and a good particle-identification system capable of suppressing pion and proton backgrounds is required. In the E01-011 setup, two layers of water

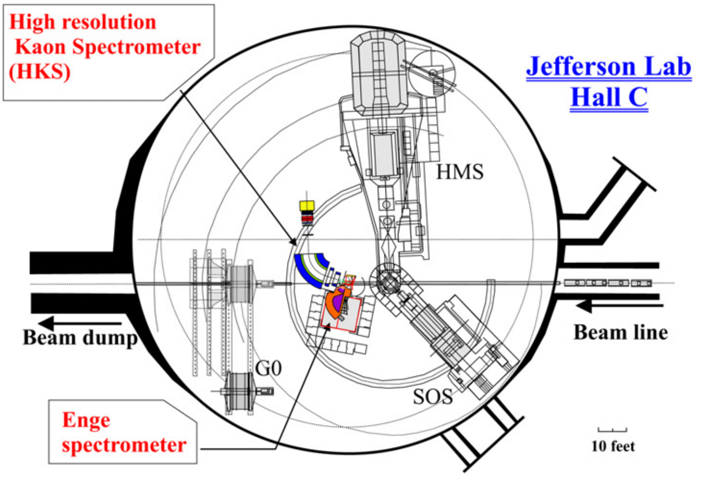

Fig. 5. Schematic drawing of the HKS spectrometer system for the $(e, e'K^+)$ hypernuclear spectroscopy experiment, E01-011.

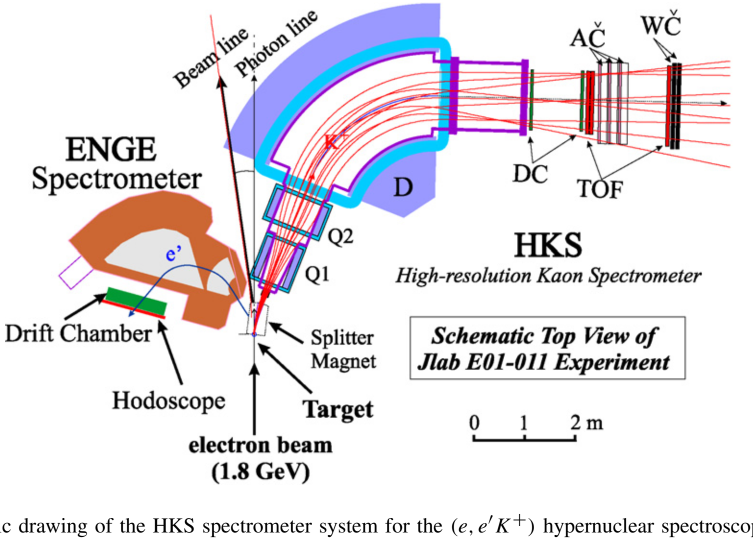

Fig. 6. Schematic drawing of the HKS spectrometer system for the $(e, e'K^+)$ hypernuclear spectroscopy experiment, E01-011.

Cherenkov counter arrays with wave length shifter ($n = 1.33$) were installed to reject protons and three layers of Aerogel Cherenkov counters ($n = 1.05$) to suppress pions. Each layer of the Water Cherenkov counter was segmented to 12 individual counters and each Aerogel counter was divided into 7 units optically separated inside the one diffusion box. They were placed behind the two sets of drift chambers and with the time-of-flight walls separated by 1 m.

In Fig. 8, approximate momentum acceptances of the scattered electron spectrometer and the HKS spectrometer are shown by a box together with the momentum correlations of kaon and scattered electron momenta for producing hyperons and Λ hypernuclei.

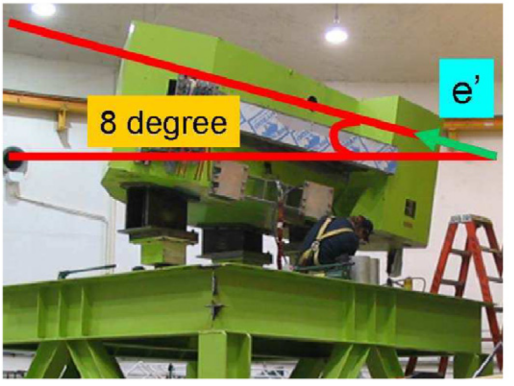

Fig. 7. A picture showing the scattered electron spectrometer is tilted by 8 degrees.

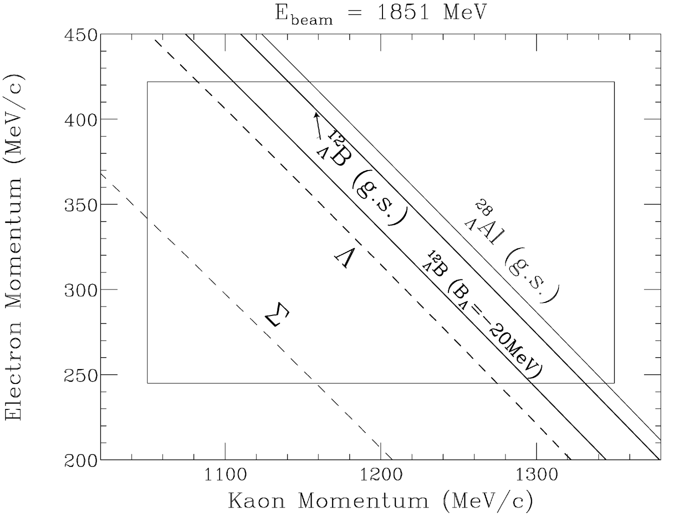

Fig. 8. Correlation of momentum acceptances of the scattered electron and kaon arms mass. The inner box represents approximate acceptance of the E01-011 spectrometer system.

4. Preliminary results of E01-011

The E01-011 experiment was carried out with CH_2, ^{12}C, ^{28}Si and ^{7}Li targets. Some exploratory rate studies were also conducted with targets such as ^{51}V in order to examine the feasibility of the future experiments for heavier hypernuclei.

In order to calibrate the spectrometer system, two calibration data sets were taken. One set is the sieve slit data for each arm, based on which scattering angle calibrations are carried out. The other set is the data with the CH_2 target. The Λ and Σ peaks serve as mass scale calibration as well as spectrometer optics calibration. It is emphasized that the wide momentum acceptances of both scattered-electron and kaon spectrometers allow us to detect Λ and Σ mass peaks simultaneously as shown in Fig. 9. The similar spectrum observed in E89-009 is also shown in the figure for comparison.

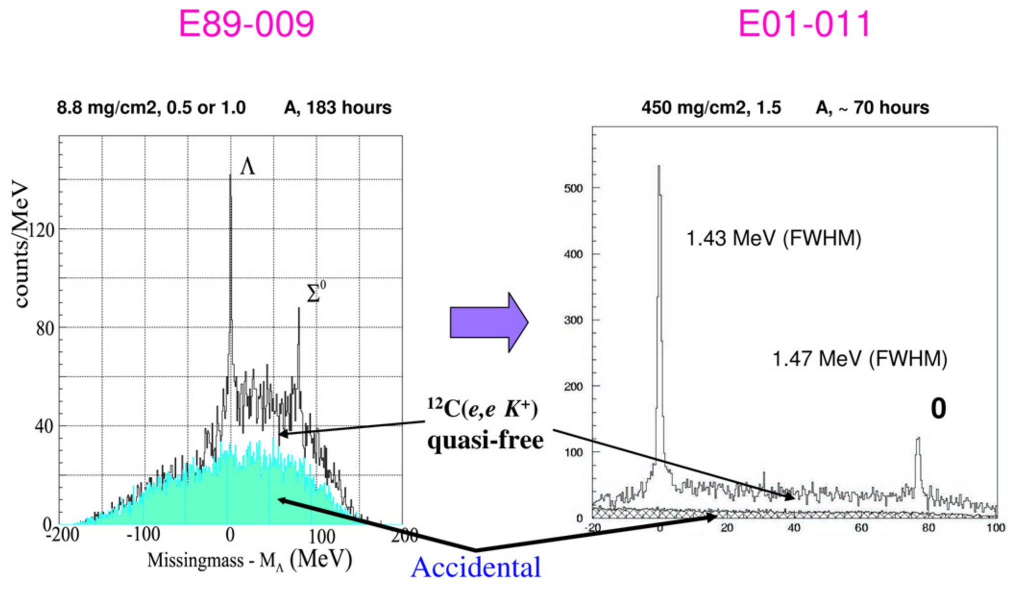

Fig. 9. Preliminary spectrum of Λ and Σ in the $p(e, e'K^+)\Lambda(\Sigma^0)$ reactions on a CH_2 target.

Together with data taken with the sieve slits in the scattered electron and kaon arms, the mass peaks of Λ and Σ hyperons provide basic calibration information. The widths of the Λ and Σ are mostly due to kinematical broadening governed by the angular resolution.

Although the tuning process is under way, preliminary spectra for $^{12}_{\Lambda}$B observed on the ^{12}C target and for $^{28}_{\Lambda}$Al on the ^{28}Si (enriched) target are presented in Figs. 10 and 11.

In the $^{12}_{\Lambda}$B spectrum, a clean hypernuclear mass spectrum with two prominent peaks corresponding to the states with a Λ hyperon in the s and p orbits was observed. The level of accidental coincidence background is controlled by the singles rates of scattered electron and kaon arms. Present mass resolution of the preliminary spectrum is as good as 700 keV. The core excited states were also observed between the two major peaks. In the present analysis, we can collect about 8 counts/hour for the $^{12}_{\Lambda}$B ground state doublet renormalizing the luminosity corresponding to the beam intensity of 30 μA and the target thickness 100 mg/cm^2.

The hypernuclear spectroscopy in the $A = 28$ mass region is expected to reveal mean field aspects of hadronic many-body system with strangeness through the structure information. It is also regarded as a gateway to the medium-heavy mass region. The preliminary spectrum also shows a ground state peak with approximately 750 keV (FWHM) resolution and reasonably good statistics. The spectrum is compared with the $^{28}_{\Lambda}$Si excitation spectrum measured by the ^{nat}Si$(\pi^+, K^+)^{nat}_{\Lambda}$Si reaction using the SKS spectrometer [12]. The spectra are compared with the latest theoretical calculation which employs the full $(sd)^n$ shell wave function [13]. It is worth mentioning that the puzzling bump structure, which was previously observed in the $(\pi^+, K^+)^{28}_{\Lambda}$Si spectrum between the two large peaks corresponding to the s and p orbits, was not evident in the present preliminary analysis.

In addition to $^{12}_{\Lambda}$B and $^{28}_{\Lambda}$Al hypernuclear spectra, $^{7}_{\Lambda}$He spectrum with the ^{7}Li target was measured. As we observe the ground state peak clearly in the preliminary analysis, we can deduce the binding energy of a Λ hyperon in the very neutron rich $^{7}_{\Lambda}$He hypernucleus. The binding energy data are expected to offer critical information on the hyperon–nucleon interactions and

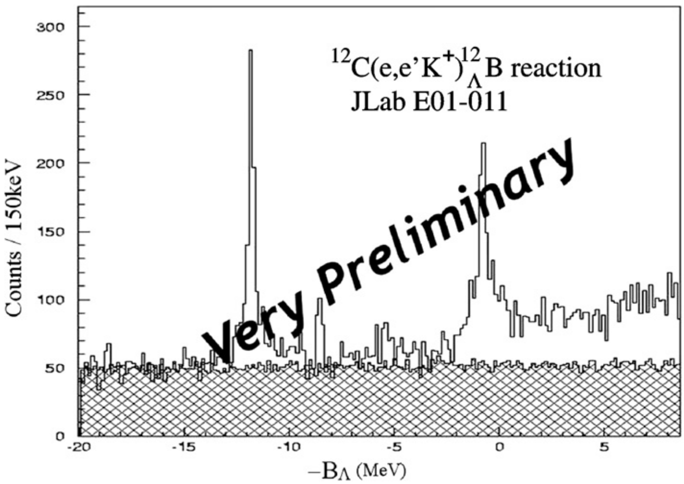

Fig. 10. Preliminary hypernuclear mass spectrum for the $^{12}C(e, e'K^+)^{12}_{\Lambda}B$ reaction.

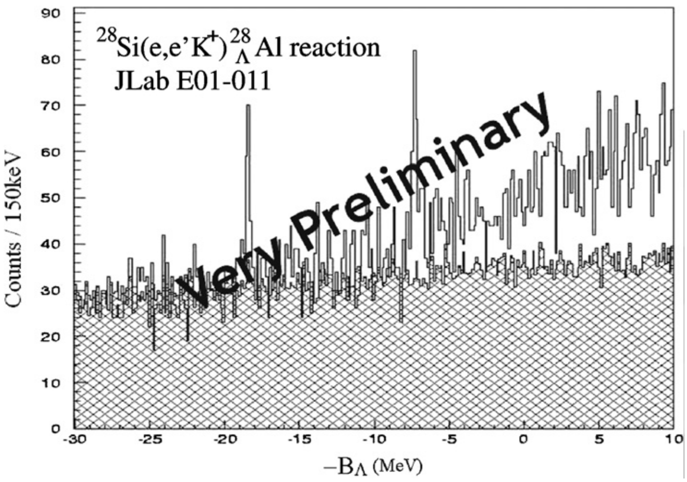

Fig. 11. Preliminary hypernuclear mass spectrum for the $^{28}Si(e, e'K^+)^{28}_{\Lambda}Al$ reaction.

$\Lambda\Sigma$ coupling through the systematic investigation of the $A = 7$ iso-triplet Λ hypernuclei, on which precision theoretical calculations are available [14].

5. The 3rd generation experiment under preparation

Although the second-generation experiment, E01-011, was successfully carried out by newly introducing the "tilt method" and using the new kaon spectrometer (HKS), Λ hypernuclei which can be studied are limited to the relatively light mass region. In order to explore hypernuclear spectroscopy by the $(e, e'K^+)$ reaction, further extending the investigation to the medium heavy mass region as well as to the light-mass region with greatly improved quality, a new proposal to study a wide-mass range of Λ hypernuclei (^{6}Li, ^{7}Li, ^{10}B, ^{11}B, ^{12}C, ^{51}V, ^{52}Cr, ^{89}Y targets)

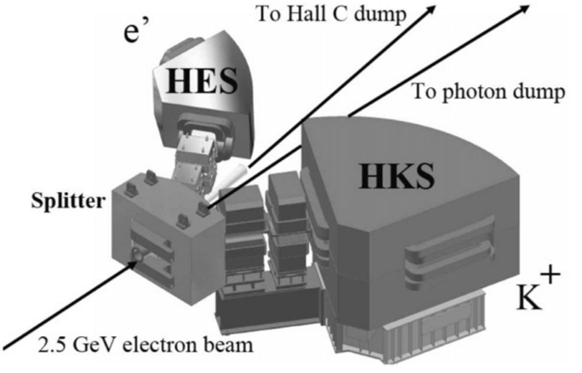

Fig. 12. The E05-115 experimental setup. The splitter magnet and e' spectrometer will be newly developed for the $(e, e'K^+)$ hypernuclear spectroscopy. The 2.5 GeV primary electron beam is pre-bent in the beamline and deflected beam by the splitter will go straight to the Hall C dump.

Table 2
HES parameters

Configuration	Q–Q–D (50 deg bend)
Central Momentum	0.55–1.0 GeV/c
Momentum acceptance	$>$ 200 MeV/c
e' angle	$>$ 2.5 deg (for 1.0 GeV/c)
Solid angle	10 msr (with SPL)
Spectrometer tilt angle	0–10 deg

with a new high-resolution electron spectrometer was submitted to JLab PAC28 and was partly accepted as JLab E05-115 [15].

In Fig. 12, a schematic drawing of E05-115 setup is shown. A new splitter magnet and a high resolution electron spectrometer (HES) are constructed and a new hypernuclear spectrometer system are formed combining the HKS spectrometer for the kaon arm. One of the most important constraints in the design of the E05-115 experiment is that the successful HKS optics should not be destroyed by the introduction of a new splitter and HES. Therefore, the new splitter magnet has pentagon shaped pole to keep the optics for the K^+ arm.

The HES consists of QQD magnets and is basically a smaller version of the HKS. The HES accepts scattered electrons in the momentum range of $0.55 \sim 1.0$ GeV/c while the ENGE spectrometer used in E01-011 accepts 0.35 GeV/c. Higher e' momentum acceptance allows us to use 2.5 GeV primary electron beam keeping virtual photon energy of 1.5 GeV. The bremsstrahlung and Møller scattering electron background will be reduced because of the high primary electron energy.

Table 2 summarizes the HES parameters. The tilt method successfully reduced background by a factor of 10000 in E01-011 experiment and it will be adopted in E05-115 experiment again. The dispersion of the splitter magnet is quite large at the entrance of HES, and thus the position of the HES relative to the splitter magnet should be carefully adjusted depending on the central e' momentum. Once primary beam energy is determined, the position of HES is determined. The tilt angle ($0 \sim 10$ deg) is optimized to accept the scattered electrons with the emission angle of $>$ 2.5 degrees so as to reduce electron background.

The expected solid angle of HES is more than twice larger than that of the ENGE spectrometer used in the previous E01-011 experiment. Furthermore, the gain of the virtual photon tagging efficiency is much larger than the gain of the solid angle because the electrons associated with the virtual photon production have forward-peaked angular distribution. Thus, the virtual photon yield gain is expected as large as a factor of 8 compared to the case of E01-011.

Construction of the HES magnets has been completed and the field mapping has been finished in Japan. The magnets were shipped to JLab and they are to be delivered to the JLab site by the end of January 2008.

6. Summary and future of the JLab hypernuclear programs

Among experimental studies of Λ hypernuclei, both reaction spectroscopy and γ-ray spectroscopy have made significant progress in the past years mainly with the use of meson beams [1]. Very recently, the $(e, e'K^+)$ reaction was successfully employed for the spectroscopy experiment of Λ hypernuclei at Jefferson Laboratory for the first time. Contrary to the meson-induced reactions, the $(e, e'K^+)$ reaction has a few advantages. Among them, it is experimentally important that hypernuclear mass resolution as good as a few to several hundreds keV could be achieved thanks to high-quality primary beams of electrons.

The hypernuclear program at JLab was initiated by the successful pilot $(e, e'K^+)$ hypernuclear spectroscopy experiment (E89-009) [10,11] with high-quality CW electron beams. The second generation $(e, e'K^+)$ spectroscopy has been carried out with the HKS spectrometer newly instgalled in Hall C. Though E89-009 suffered from low luminosity and limitation of both solid angle and resolution of the existing kaon spectrometer (SOS), it proved that the $(e, e'K^+)$ reaction can be a quite promising tool for Λ hypernuclear study.

The second generation experiment (E01-011) was performed at Hall C (E01-011) with advanced experimental technique such as a newly designed high resolution kaon spectrometer (HKS) and a new configuration for the scattered electron spectrometer (tilt method). The second generation experiments preliminarily proved high hypernuclear-mass resolution (< 700 keV, FWHM) in excitation energy spectra for light hypernuclei such as $^{7}_{\Lambda}$He, $^{9}_{\Lambda}$Li, $^{12}_{\Lambda}$B, $^{16}_{\Lambda}$N, and $^{28}_{\Lambda}$Al.

The third generation experiments are now in preparation with what we learned from the second generation experiments. Hall C collaboration introduces a new high resolution electron spectrometer (HES) with an intention to fully explore hypernuclear spectroscopy taking advantages of the $(e, e'K^+)$ reaction. A proposal to investigate wide mass range of hypernuclei (^{6}Li, ^{7}Li, ^{9}B, ^{10}B, ^{12}C, ^{51}V, ^{52}Cr, ^{89}Y targets) with a new HES spectrometer was approved as E05-115 by JLab PAC28. The wide acceptance of HES and better matching of HKS and HES spectrometers will improve the hypernuclear yield by more than factor of 5. The tilt method which worked efficiently in E01-011 will be applied to the HES in order to suppress high rate electron background from bremsstrahlung and Møller scattering. It is essentially important for the heavier targets.

Table 3 compiles the evolution of the JLab hypernuclear experiments from the first generation to the third generation experiments. It can be seen that better hypernuclear yield and resolution are obtained for the second generation experiments with improved experimental techniques.

The time-line of the JLab Hall C hypernuclear program is given in Table 4 together with Hall A program. The Hall C Collaboration completed the construction of the new HES spectrometer and the E05-115 experiment will be ready for staging the HKS/HES hypernuclear spectrometer system at the beginning of 2009.

Table 3
Evolution of the JLab hypernuclear experiments

	E89-009 Hall C	E94-107 Hall A	E01-011 Hall C	E05-115 Hall C
Spectrometer	SOS+ ENGE+ SPL	HRS+ HRS+ Septum	HKS+ ENGE+ SPL	HKS+ HES+ newSPL
Beam Intensity (μA)	0.7	100	24	30–100
Target Thickness (mg/cm^2)	22	100	100	100
Hypernuclear Yield ($^{12}_{\Lambda}B_{gs}$/hour)	0.5–0.9	2–4	8–10	(40–100)
Resolution (keV, FWHM)	750	650	< 700	(300–400)
Beam Energy (GeV)	1.8	4	1.8	2.5
Virtual Photon Energy (GeV)	1.5	2.4	1.5	1.5
K central momentum (GeV/c)	1.2	2.0	1.2	1.2
e' central momentum (GeV/c)	0.3	1.6, 1.9	0.35	1.0
K detection angle (deg)	0–7	6	1–13	1–13
e' detection angle (deg)	0	6	4.5	> 2.5

Table 4
Time-line of the JLab hypernuclear programs

Year	Hall A	Hall C
2000		E89-009 Beam Time
		JP Gov. approved HKS
2003		HKS shipped to JLab
2004	E94-107(1) Beam Time	JP Gov. approved HES
2005	E94-107(2) Beam Time	E01-011 Beam Time
		E05-115 approved
2006		HES Design and construction
2007	PR07-107 approved	HES shipped to JLab
		HES preparation
2008		PR08-002 submitted
		(E05-115 extension)
		E05-115 preparation
200X	(E07-107 Beam Time)	E05-115 Beam Time

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