Spectroscopic investigation of Λ hypernuclei in the wide mass region using the $(e,e'K^+)$ reaction

2011 J. Phys.: Conf. Ser. 312 092047

(http://iopscience.iop.org/1742-6596/312/9/092047)

Journal of Physics: Conference Series **312** (2011) 092047 doi:10.1088/1742-6596/312/9/092047

Spectroscopic investigation of Λ hypernuclei in the wide mass region using the (e,e'K$^+$) reaction

Satoshi N. Nakamura on behalf of JLab E05-115 collaboration
Graduate School of Science, Tohoku University, SENDAI, Miyagi, 980-8571, JAPAN
E-mail: nue@lambda.phys.tohoku.ac.jp

P. Achenbach, A. Ahmidouch, I. Albayrak, D. Androic, A. Asaturyan, R. Asaturyan, O. Ates, R. Badui, P. Baturin, W. Boeglin, J. Bono, P. Bosted, E. Brash, P. Carter, C. Chen, A. Chiba, M. Christy, M. Dalton, S. Danagoulian, R. De Leo, D. Doi, K. Egiyan, M. Elaasar, R. Ent, H. Fenker, Y. Fujii, M. Furic, M. Gabrielyan, L. Gan, F. Garibaldi, D. Gaskell, A. Gasparian, T. Gogami, O. Hashimoto, T. Horn, B. Hu, M. Jones, H. Kanda, M. Kaneta, S. Kato, M. Kawai, D. Kawama, H. Khanal, M. Kohl, A. Liyanage, W. Luo, D. Mack, K. Maeda, A. Margaryan, G. Marikyan, P. Markowitz, T. Maruta, A. Matsumura, V. Maxwell, A. Mkrtchyan, H. Mkrtchyan, S. Nagao, S.N. Nakamura, A. Narayan, T. Navasardyan, C. Neville, G. Niculescu, M.-I. Niculescu, A. Nunez, Nuruzzaman, Y. Okayasu, T. Petkovic, J. Pochodzalla, X. Qiu, J. Reinhold, V. Rodriguez C. Samanta, B. Sawatzky, D. Schott, T. Seva, A. Shichijo, G. Smith, V. Tadevosyan, H. Tamura, L. Tang, N. Taniya, V. Tvaskis, M. Veilleux, W. Vulcan, F.R. Wesselmann, S.A. Wood, T. Yamamoto, L. Ya, Z. Ye, K. Yokota, L. Yuan, S. Zhamkochyan and L. Zhu
JLab E05-115 (HKS-HES) collaboration

Abstract. The third generation spectroscopic study of Λ hypernuclei using (e,e'K$^+$) reaction (JLab E05-115) was performed at JLab Hall-C in 2009. The experiment introduced the newly developed high-resolution electron spectrometer (HES) with the existing high-resolution kaon spectrometer (HKS). Experimental configuration, conditions, spectrometer designs and current status of analysis are presented.

1. Introduction

Spectroscopic study of Λ hypernuclei by the (e,e'K$^+$) reaction has unique advantages over those through meson-induced reactions such as (π^+, K$^+$) and (K$^-$, π^-). Contrary to the meson-induced reactions, the (e,e'K$^+$) reaction favorably excites spin-flip Λ hypernuclear states and produces neutron rich Λ hypernuclei converting a proton to a Λ hyperon. From the experimental point of view, it is also of significant importance that the reaction allows us to improve the energy resolution down to sub-MeV taking advantage of a high-quality primary beam.

The sub-MeV energy resolution is a key for developing the 21st century hypernuclear spectroscopy program. To this end, the first (e,e'K^+) hypernuclear spectroscopy experiment was carried out successfully at Jefferson Lab's (JLab) Hall C in the spring of 2000 by the E89-009 collaboration (HNSS). This pioneering experiment demonstrated the great potential of the (e,e'K^+) reaction, obtaining a hypernuclear mass spectrum with an energy resolution of about 750 keV(FWHM) in the ^{12}C(e,e'K^+)$^{12}_{\Lambda}$B reaction [1, 2]. However, it was also made clear that an improvement of this hypernuclear spectrometer system is vitally needed to fully explore the potential. In particular, it was recognized, even before the E89-009 experiment started, that a new high-efficiency high-resolution kaon spectrometer is required.

In the course of the above efforts, a new kaon spectrometer, HKS, was designed with an intention to realize both large detection efficiency and high-resolution, simultaneously. At the same time, a new experimental configuration, 'tilt method', was adopted so that very forward electrons associated with Bremsstrahlung process can be avoided and therefore a higher luminosity ($\propto$ target thickness $\times$ beam intensity) can be accepted. The second generation experiment, E01-011, took data in year 2005 and it proved that HKS achieved the designed performance and the tilt method successfully reduced the electron background [3].

In 2005, a new proposal of the third generation experiment was submitted to PAC28 and accepted as E05-115 [4]. The experiment, E05-115 adopts HKS and the tilt method and furthermore the newly designed high-resolution electron spectrometer, HES. Introduction of new HES and SPL in addition to HKS allows us to measure medium heavy $^{52}_{\Lambda}$V hypernucleus of which electron background becomes more than 10 times severer than $^{12}_{\Lambda}$B measurement.

The data taking of E05-115 with HKS and HES was successfully finished in year 2009. In this paper, experimental conditions of E05-115 and current status of data analysis are summarized.

2. Experimental configuration and condition

The first generation E89-009 experimental setup accepted reaction electrons and kaons at angles including zero degrees. In this configuration, the event accumulation rate was limited by the accidental background rate from Bremsstrahlung and Mϕller electrons at very forward angles. Therefore, we proposed to tilt the electron spectrometer by a small angle sufficient to exclude electrons from the Bremsstrahlung and Mϕller processes.

A plan view of the E05-115 geometry, which consists of a new splitter magnet (SPL), a newly designed high-resolution electron spectrometer (HES) and the high-resolution kaon spectrometer (HKS) which was used for the second generation experiment (E01-011), is shown in figure 1. Both the HKS spectrometer and the HES spectrometer were positioned at angles as forward as possible, but avoided the 0-degree electrons and positrons. The HKS spectrometer for the kaon arm has a QQD configuration. It has a momentum resolution of 2×10^{-4} at 1.2 GeV/c and a solid angle acceptance of $\sim$ 10 msr, when it is used with the newly designed SPL.

The design principle of HES follows that of HKS, with a QQD configuration. The charge separation magnet, SPL, was also newly designed to make best matching between HKS and HES. In the present experimental setup, HES was vertically tilted to accept only the electrons with an scattering angle larger than 4.5 degrees so that a major part of Bremsstrahlung electrons and the Mϕller scattered electrons did not enter the spectrometer acceptance. Since the optics of the SPL + HES system are modified due to the tilt, it becomes necessary to measure not only positions but also incident angle of the particle trajectory at the focal plane to determine the momentum with sufficient precision. Therefore, we operated honeycomb-cell structure drift chamber (EDC1) which had been used in E01-011 and an additional planar drift chamber (EDC2).

Table 1 summarizes the configuration and specification of the E05-115 hypernuclear spectrometer systems.

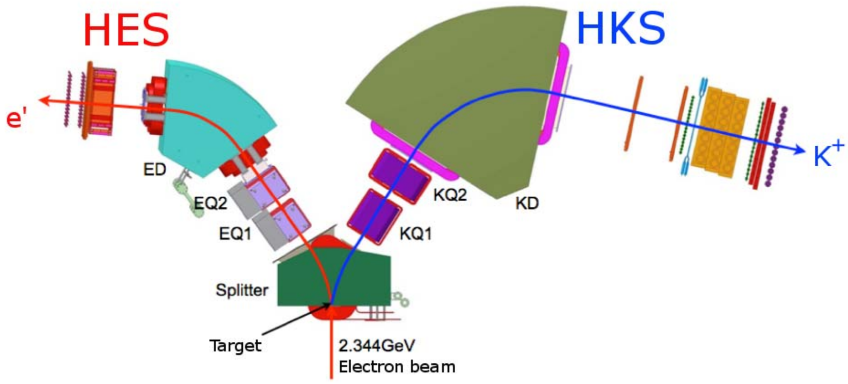

Figure 1. Plan view of the high-resolution kaon spectrometer (HKS) and a new high-resolution electron spectrometer (HES) for the E05-115 experiment.

Table 1. Experimental condition and specification of the E05-115 hypernuclear spectrometers

Beam condition	
Beam energy	2.344 GeV
Beam energy stability	$< 7 \times 10^{-5}$ (FWHM)
General configuration	Splitter+Kaon spectrometer+Electron spectrometer
Kaon spectrometer (HKS)	
Configuration	QQD and horizontal bend
Central momentum	1.2 GeV/c
Momentum acceptance	$\pm$ 12.5 % (1.05 – 1.35 GeV/c)
Momentum resolution ($\Delta p/p$)	2×10^{-4} (FWHM)
Solid angle acceptance	10 msr with SPL
Kaon angular coverage	0 - 14 degrees
Electron spectrometer (HES)	
Configuration	QQD and horizontal bend
Central momentum	0.844 GeV/c
Momentum acceptance	$\pm$ 17 % (700 – 988MeV/c)
Momentum resolution ($\Delta p/p$)	2×10^{-4} (FWHM)
Tilt Angle	Vertical : 6.5 degrees*
Solid angle acceptance	7 msr with a new splitter
Angular coverage	3 - 14.5 degrees (w/o collimator)

* The 6.5 degrees tilt of the spectrometer matches to select electrons with a scattering angle larger than 4.5 degrees with a collimator.

3. Spectrometer and beamline design

The design parameters of the spectrometers to achieve the experimental goal are summarized in Table 1. In this section, the spectrometers' design and newly constructed JLab Hall-C chicane beamline will be explained.

3.1. High-resolution Kaon Spectrometer (HKS)

The HKS consists of two quadrupole magnets (KQ1 and KQ2) and one dipole magnet (KD). Due to two degrees of freedom of the quadrupole doublet, the horizontal and vertical focusing can be adjusted simultaneously. The HKS is designed to achieve both 2×10^{-4} momentum resolution and 10 msr solid angle acceptance at the same time when it is used with the new SPL magnet. The HKS is positioned at an angle of 7°, covering from 0 to 14 degrees, with respect to 1.2 GeV/c zero degrees scattered particle to avoid scattered positively charged particles at 0 degrees, mostly positrons. The momentum acceptance was designed to be ±12.5%, matching to that of the electron arm. The HKS was already used in E01-011 and its basic performance was already proven. The parameters of the HKS magnets are summarized in Table 2 (left).

Table 2. Summary of the HKS and HES magnets' parameters

KQ1 length (cm)	84	EQ1 length (cm)	60
KQ1 bore radius (cm)	12	EQ1 bore radius (cm)	10
KQ1 field gradient (T/m)	-4.45	EQ1 field gradient (T/m)	5.65
KQ1 integral field gradient (T/m·m)	-4.27	EQ1 integral field gradient (T/m·m)	3.99
KQ2 length (cm)	60	EQ2 length (cm)	50
KQ2 bore radius (cm)	14.5	EQ2 bore radius (cm)	12.5
KQ2 field gradient (T/m)	2.76	EQ2 field gradient (T/m)	-4.09
KQ2 integral field gradient (T/m·m)	2.05	EQ2 integral field gradient (T/m·m)	-2.03
KD bending angle (degrees)	70	ED bending angle (degrees)	50
Radius of KD magnet center (cm)	270	Radius of ED magnet center (cm)	220.0
KD gap (cm)	20	ED gap (cm)	19.4
KD field (T)	1.44	ED field (T)	1.21
HKS central momentum (GeV/c)	1.20	HES central momentum (GeV/c)	0.844

3.2. High-resolution Electron Spectrometer (HES)

The ENGE spectrometer used in E01-011 was replaced by a new high-resolution electron spectrometer HES. The basic design of the HES spectrometer follows that of HKS. The HES consists of two quadrupole magnets (EQ1 and EQ2) and one dipole magnet (ED). Due to two degrees of freedom of the quadrupole doublet, the horizontal and vertical focusing can be adjusted simultaneously. The HES was designed to achieve both 2×10^{-4} momentum resolution and 7 msr solid angle acceptance at the same time when it is used with the new SPL. The parameters of HES are summarized in Table 2 (right).

In the pilot (e,e'K) hypernuclear experiment, E89-009, the electrons associated with Bremsstrahlung dominated the background in the scattered electron spectrometer. The method to suppress the Bremsstrahlung background was to use the difference of the angular distributions between Bremsstrahlung electrons and scattered electrons associated with the virtual photons which contribute to kaon production. The tilt method had been applied in E01-011 and successfully reduced the Bremsstrahlung background by a factor of 10000. We adopted the tilt method again for E05-115.

4. Beamline configuration

Since the target is placed in the SPL magnet the Hall-C beamline to guide scattered electrons (e') to HES and K^+s to HKS, the deflected primary beam needs to be bent back to the Hall-C dump. In the second generation experiment, E01-011, we employed so called post-chicane configuration; beam was guided to the target by a straight beamline and bent by 8.2 degree in the splitter magnet, then finally two dipole magnets kicked the beam back to the Hall-C dump direction. This configuration had the advantage of being able to combine dumps for both beam and photon originating from Bremsstrahlung at the target, however, huge background was generated around post-chicane area due to electron halo hitting post-beamline apparatus.

For E05-115, we constructed pre-chicane configuration as shown in figure 2. The beam was horizontally kicked at the entrance of Hall-C by the DZ magnet and bent back by two dipole magnets (FZ1, 2). The primary beam was guided to the target through the correction magnet DW at the angle of 15.17 degrees so that the beam was deflected back in SPL by the same angle and went straight to the Hall-C dump. Pre-chicane option enabled us to make chicane components smaller and transport beam cleanly. However, the photon dump had to be prepared separately from the Hall-C dump and special care to beam orbit tune was necessary to control directions of four output beams from the SPL magnet (scatter e', unused primary beam, Bremsstrahlung photon and K^+) .

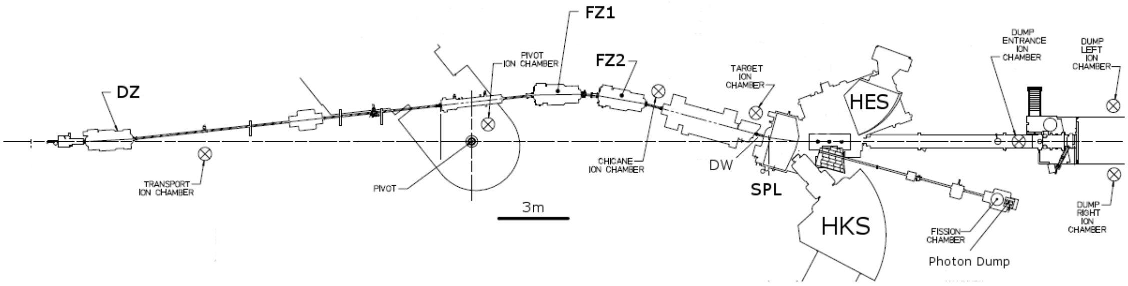

Figure 2. Pre-chicane beamline newly constructed in JLab Hall-C.

5. Targets

In E05-115, solid targets and a water cell target were used. Table 3 summarizes these targets. The remote-controlled target ladder was inserted at an angle of 17° and thus a correction factor of 1/(cos 17°) should be taken into account to obtain the effective target thickness.

Table 3. The list of targets used in E05-115

Target	Thickness* [mg/cm^2]	Note
CH_2	451	Raster $3^v \times 1^h$ mm^2
H_2O	500	with Harvar windows
^{7}Li	184	Isotopically enriched
^{9}Be	188	100%
^{10}B	114	Enriched to 99.9 %
^{12}C	100	Purity : 98.9 %
^{52}Cr	125	Enriched to 99.9 %
BeO	143	Purity : 99.5%

*To obtain effective target thickness, 1/(cos 17°) should be multiplied to the target thickness.

In E01-011, high-density CH_2 target was used as a proton target. The proton target is important for study of elementary strangenss electro-production but also for the absolute energy calibration by using known Λ and Σ^0 masses. CH_2 is solid and easy to handle without any window in vacuum, however, the melting point of the CH_2 is quite low ($\sim$ 130°C) and even rastered low intensity beam ($\sim 2\mu$A) burned the target so that hydrogen escaped from the CH_2 target. We monitored hydrogen concentration by using Λ yield during beamtime and target was periodically replaced by a new one when it became 60% of the original yield. In addition to

CH_2 target, a water-cell target was introduced in E05-115. Water circulated in a closed loop and it serves as cooling water as well. The windows of the water cell target were made of 25μm thick of Havar (Be, Co, Cr, Fe alloy) sealed by indium wires. The window can stand for 125 psi pressure. The CH_2 target with a low current beam provided good S/N calibration data and the water cell target with a high intensity beam gave beam energy scan data in limited time. They will serve complimentary roles in the energy/kinematic calibration processes.

6. Missing mass spectrum for p(e,e'K$^+$)Λ, Σ^0

Fig. 3 shows a preliminary missing mass spectrum for CH_2 target. Without serious optics tuning of spectrometers, Λ and Σ^0 peaks were clearly seen ($\sigma \sim 1.5$ MeV). This spectrum shows that all detectors and spectrometer systems are basically working as we expected even though further detailed analyses are necessary to achieve designed resolution ($<$ 500 keV, FWHM) for hypernuclear masses. For hypernuclear spectrum, existing analysis codes especially tracking routines need to be improved due to newly introduced multistop TDCs (time-to-digit converters) and increased multiplicity. Analysis works including adequate handling of multihits and optics tuning of spectrometers are now in progress.

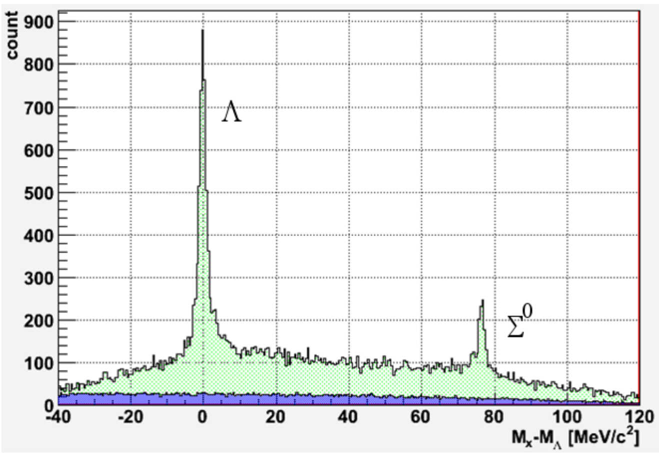

Figure 3. Missing mass spectrum for CH_2 target with a subtraction of Λ's mass. Accidental background is shown as hatched region. Remaining events under hyperon peaks are originating from quasi-free hyperon production from carbon.

Acknowledgments

Support of the Accelerator and Physics Division of Thomas Jeffeson National Laboratory (JLab) is greatly acknowledged. The program is partly supported by Japan-MEXT Grant-in-aid for Scientific Research (16GS0201, 15684005, 12002001, 08239102, 09304028, 09554007, 11440070, 15204014), Japan-US collabrative research program, Core-to-core program (21002) and young researcher overseas visits program for vitalizing brain circulation (R2201) by JSPS, US-DOE contracts (DE-AC05-84ER40150, DE-FG02-99ER41065, DE-FG02-97ER41047) and US-NSF (013815).

References

[1] T. Miyoshi *et al.*, Physical Review Letter **90** (2003) 232502.
[2] L. Yuan *et al.*, Physical Review **C 73** (2006) 044607.
[3] O. Hashimoto *et al.*, Nuclear Physics **A 835** (2010) 121.
[4] O. Hashimoto, L. Tang, J. Reinhold, S.N. Nakamura *et al.*, JLab E05-115 Proposal (2005).