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The HKS experiment on Λ-hypernuclear spectroscopy via electroproduction at JLab

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The HKS (Jlab E01-011) experiment on spectroscopy of Λ-hypernuclei using (e,e'K$^+$) reaction was successfully carried out in 2005. This paper gives a brief description of the experiment and its technique and shows some of the preliminary spectra that are still under analysis.

The first spectroscopic experiment (JLab E89-009/HNSS) on Λ-hypernuclei using continued wave electron beam was done in Hall C at Thomas Jefferson National Accelerator Facility (JLab) in 2000[1]. The experiment demonstrated that a sub-MeV energy resolution and a reasonably high production yield can be achieved because of the precision and power of the beam such as that at JLab. This made the electroproduction so attractive since not only it should produce new spectroscopy dominated by deeply bound spin-flip states but also can have the mass spectroscopy from light to at least medium heavy hypernuclei with the best precision. In addition, all the so produced Λ-hypernuclei are neutron rich due to conversion of proton into Λ.

The biggest challenge experienced from HNSS was an extremely high electron rate near zero degree scattering from Bremsstrahlung and Mϕller processes. Since in the primary p(e,e'K$^+$)Λ reaction that converses a p into Λ inside nucleus the scattered electron and kaon must be detected in coincidence, the high e rate caused a high accidental coincident background in the measured mass spectroscopy. This also constrained the HNSS

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experiment to use low luminosity thus had low physics yield.

Inspired from the achievement of HNSS, the follow up HKS experiment made a major equipment upgrade and a key modification to the experimental technique[2]. The experiment aimed to (1) further improve the energy resolution, (2) dramatically increase the production yield, and (3) significantly reduce the accidental background. These three key goals are fundamental to the hypernuclear program using electromagnetic probes.

The major equipment upgrade was replacing the Hall C standard Short Orbit Spectrometer (SOS) used in HNSS by a new high resolution kaon spectrometer (HKS). HKS has three times larger solid angle acceptance ($\sim$15 mrs) than SOS has. A wide Center-of-Mass angular coverage can be obtained with a fixed spectrometer position. The central angle of HKS is at 6 degrees with respect to the beam direction and covers about 10 degrees in the reaction plane. Its momentum resolution is expected to be twice better than that of SOS.

The yield gain and accidentals reduction were mainly accomplished by the new geometry of the electron arm (Enge spectrometer) in comparison to that used in HNSS. It was tilted 7.75 degrees in the direction normal to the electron scattering plane but aimed to a virtual target point lower than the real target position. The geometry was such selected that electrons from near zero degrees were blocked and the central angular acceptance was set at a finite angle. At this geometry the background electron rate decreased dramatically by a factor of $\sim$400, much more than the reduction of the tagged virtual photon flux rate. This allowed the HKS experiment to run with high luminosity to gain higher physics yield while maintaining a background electron rate 100 times lower than that of HNSS. This combined effect reduced the accidental background level in the mass spectra thus improved the quality of the data.

New detectors were built for both arms and tested using Test Beam at KEK before the HKS experiment. The time counters in both arms were able to provide a good real coincidence time selected within 2ns beam pulse separation. The shape of accidental background could be analyzed from events selected from the accidental coincidence time peaks. Tracking chambers in both arms handled well for a particle rate of $\sim$10-20 MHz within the active area of $\sim$0.3 m^2. The Time-of-flight (TOF) counters, the three layers of Aerogel Č erenkov counters, and two layers of water Čerenkov counters provided excellent kaon identification against protons, positive pions, and positrons.

To obtain precise mass spectra in term of Λ binding energy and good energy resolution, the experimental kinematics and spectrometer optics must be calibrated and optimized carefully. The kinematics can broaden the peak width of the observed states and shift the binding energy scale. They come from imperfect knowledge of absolute central beam energy, central momentum of the two spectrometers, and the target struggling for e, e', and K^+. Since a single separation dipole magnet (Splitter) was used right after the target to bend the forward scattered e' and K^+ in opposite directions in gaining a larger separation angle, the spectrometers cannot be calibrated with respect to beam separately. The calibration was done using physical events from well known and well observed states.

The HKS experiment could measure the bound hypernuclear states as well as Λ and Σ particles from different targets in one experimental kinematics. Correct kinematics will minimize the peak width of all single particle states and obtain correct masses of well known Λ and Σ particles at the same time. Therefore, the calibration process is a

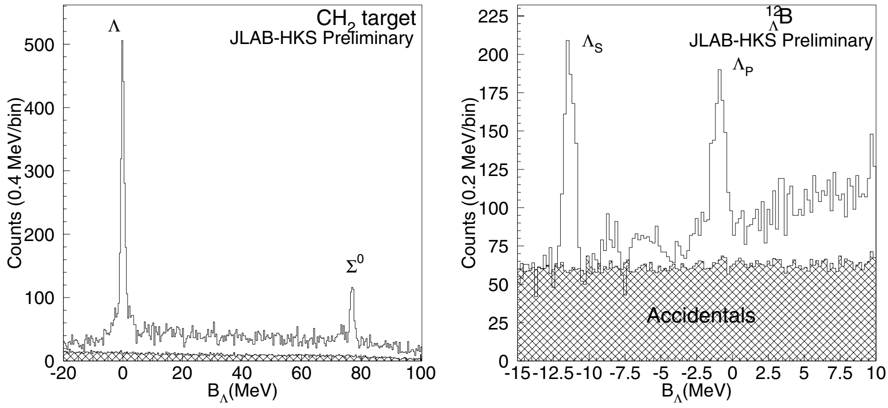

Figure 1. Left: Preliminary spectrum of Λ and Σ^0 obtained from the p(e,e'K$^+$)$\Lambda(\Sigma^0)$ reaction using a CH_2 target. Right: Preliminary spectrum of ${}^{12}_{\Lambda}$B hypernuclei obtained from about 90 hours of beam time with current of 30 μA.

minimization process to the peak widths and the mass deviations of reconstructed Λ and Σ particles. All the kinematics effects and the optical optimization must be done in an iterative fashion to reach converged result. However, the contribution of the background events within the selected particle states can reduce the effectiveness of the method and increase the difficulty in reaching a reliable converging result. Currently, the calibration process is not yet completed and the resulted spectroscopy is still very preliminary. The left figure in Fig. 1 shows the spectrum of Λ and Σ obtained from the p(e,e'K$^+$)$\Lambda(\Sigma^0)$ reaction using a CH_2 target. It is plotted in term of Λ binding energy. Comparing to the HNSS experiment, the yield rate increased by 15 times while the signal/accidental (S/A) ratio improved by a factor of 5. Events selected from these two masses are used in the calibration process effectively.

The right figure in Fig.1 shows the preliminary spectrum of ${}^{12}_{\Lambda}$B hypernuclei plotted in term of Λ binding energy. The spectrum is in good agreement with that obtained in HNSS but with more than three times statistics obtained in much shorter time. The new spectrum shows clear evidence of core excited states between the two dominant states, representing the Λ in s and p shells coupled with a core ^{11}B at ground state, respectively. Both these two peaks are believed to be composed by at least two close-by states. Detailed physics analysis will be done after the spectrum is finalized.

The preliminary ${}^{28}_{\Lambda}$Al spectroscopy is illustrated in the left figure in Fig.2. The states with Λ at s- and p-shells with respect to the core can be clearly identified. There are strengths in between the states and behind p-shell state in the bound region. They may represent a mixing of variety of excited states with different particle-hole configurations.

The spectrum of ${}^{7}_{\Lambda}$He is shown in the right figure in Fig.2. The spectrum shows clearly the ground state observed for the first time. There may be evidence for excited states

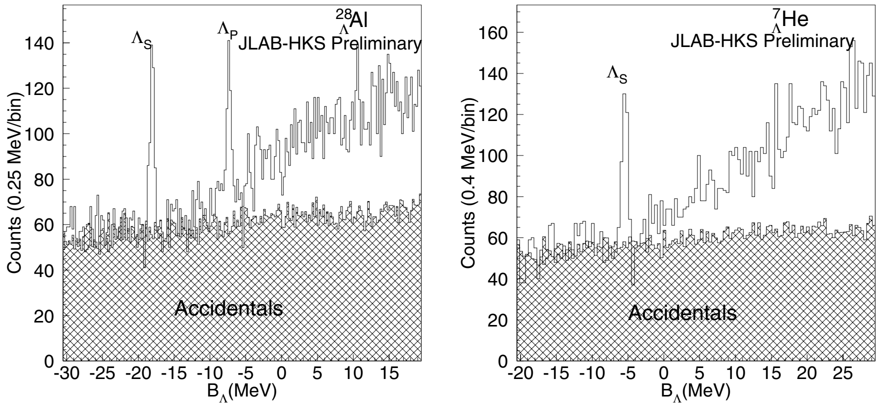

Figure 2. Left: Preliminary spectrum of $^{28}_{\Lambda}$Al hypernuclei obtained from about 140 hours of beam time with current of 13 μA. Right: Preliminary spectrum of $^{7}_{\Lambda}$He hypernuclei obtained from about 30 hours of beam time with current of 30 μA.

just below threshold. The spectrum is significant because this is the lightest neutron rich Λ-hypernuclear system.

There were other spectra obtained from ^{6}Li, ^{9}Be, ^{10}B, ^{51}V, and ^{89}Y targets in this experiment. They were all test runs with short beam time aiming to confirm the production rate for future experiments. They will be analyzed after the calibration process completes.

In summary, the HKS experiment successfully demonstrated the new experimental technique that aimed to optimize the experiment using the high intensity primary electron beam. The next phase experiment, E05-115[3], will replace the Enge spectrometer with another new large acceptance electron spectrometer. The new upgrade allows the experiment to use higher beam energy, larger electron solid angle with better background suppression, and better optics. We anticipate that the yield as well as the S/A ratio will further improve. The study will focus on heavy systems while the study of some light systems can be also done in short running time.

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