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Future hypernuclear program at JLab Hall C

JLab E01-011 Collaboration

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Abstract

Encouraged by the success of the first hypernuclear spectroscopy through the $(e, e'K^+)$ reaction (JLab E89-009), a new improved experiment with a newly developed High resolution Kaon Spectrometer (HKS) and a new configuration of the electron spectrometer is planned at the JLab Hall C.

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The introduction of the HKS will improve by a factor of two, the energy resolution which was limited by the previous kaon spectrometer. The hypernuclear yield and the signal to noise ratio will be also improved by a factor of 50 and 10, respectively.

1. Introduction

So far, Λ hypernuclei have been extensively studied by using meson-induced reactions, such as (π^+, K^+) and (K^-, π^-). The $(e, e'K^+)$ reaction is a new method for hypernuclear spectroscopy, and it has unique advantages over previous meson-induced reactions. For example, 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 a great advantage that a high-quality electron beam allows us to improve the energy resolution down to sub-MeV levels.

The first $(e, e'K^+)$ hypernuclear spectroscopy experiment was carried out successfully at the JLab Hall C in the spring of 2000 by the E89-009 Collaboration. This pioneer experiment demonstrated a great potential of the $(e, e'K^+)$ reaction, obtaining a hypernuclear mass spectrum with an energy resolution of about 900 keV (FWHM) in the $^{12}C(e, e'K^+)^{12}_{\Lambda}B$ reaction [1]. However, the data suffer from poor signal to noise ratio (~ 1) and limited statistics. It is clear that an improvement of this hypernuclear spectrometer system is essential to fully explore the potential of the new reaction to study hypernuclear structure.

For this purpose, the E01-011 Collaboration proposed a new experiment with a newly developed HKS spectrometer which is designed for $(e, e'K^+)$ hypernuclear spectroscopy.

2. Experimental principle

Fig. 1 shows a schematic view of the E01-011 setup. The basic configuration of the E01-011 experiment is similar to that of E89-009. The beam energy (1.8 GeV) was chosen as low as possible so as not to open unnecessary reaction channels, and to make the virtual photon energy near 1.5 GeV when accepting the approximately 300 MeV electrons that match the momentum acceptance of the electron spectrometer. The $p(\gamma, K^+)\Lambda$ cross section decreases for $E_\gamma > 1.5$ GeV [2].

The scattered electron (e′) and K^+ are separated by the dipole magnet (splitter) located just behind the target. The scattered electron will be measured by the Enge split-pole spectrometer (ENGE), which was also used for the E89-009 experiment, and the K^+ by a newly developed high resolution kaon spectrometer (HKS).

The two key experimental conditions were improved from the previous experiment: (1) introduction of the new kaon spectrometer (HKS) and (2) a new electron spectrometer geometry (tilt method).

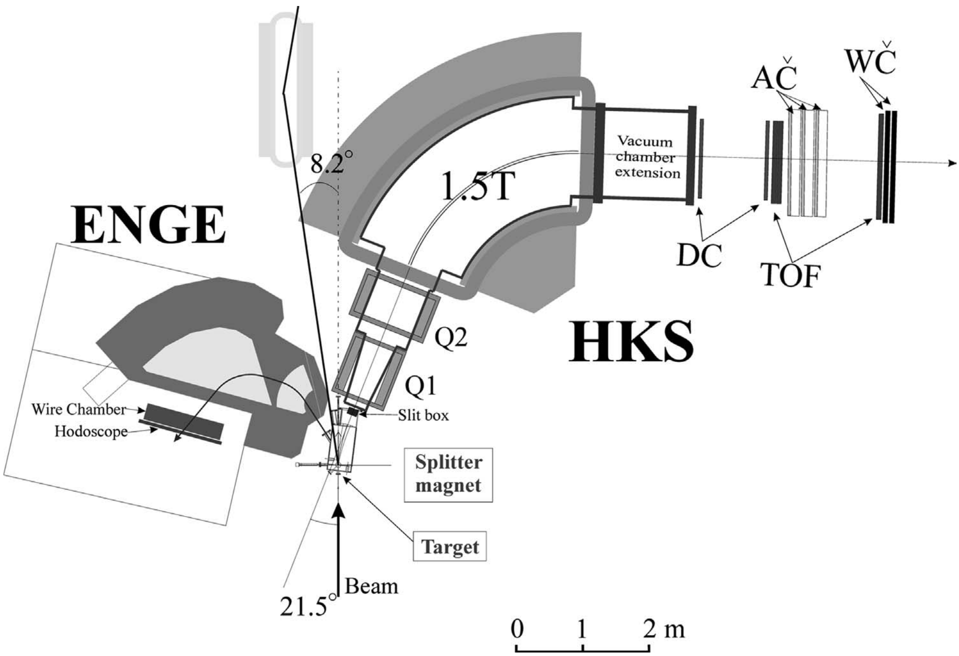

Fig. 1. Schematic figure of the E01-011 setup.

Employing the proposed new experimental configuration and with the HKS spectrometer, we expect to improve both the hypernuclear yields and the signal-to-accidental ratio by one order of magnitude, while improving the energy resolution by a factor of two. The proposal of the new experiment with the HKS and the tilt method was accepted by JLab PAC19 [3].

2.1. A new high resolution kaon spectrometer (HKS)

The HKS consists of two quadrupole magnets Q1 (8.5 tons) and Q2 (10.5 tons), and one dipole magnet D (210 tons). Due to two degrees of freedom of the quadrupole doublet, the horizontal and vertical focusing can be simultaneously adjusted. The HKS is designed to achieve both 2×10^{-4} momentum resolution and 16 msr solid angle acceptance when it is used with the splitter. It means that the HKS spectrometer will have 3 times greater solid angle and twice better resolution than the previous kaon spectrometer.

The HKS is positioned at an angle of 7° covering K^+ emission angles from 1° to 13°, with respect to the incident beam, to avoid high-rate positively charged particles (mostly positrons) produced at 0°. Basic parameters for HKS are summarized in Table 1.

The construction and the precise field mapping of the HKS magnets has been carried out at Mitsubishi, Kobe (Japan) and they were disassembled for shipping. The HKS magnets arrived at JLab in November, 2003 and the pre-assembly at the test lab is in progress (Fig. 2).

Fig. 2. HKS pre-assembly at JLab test lab (December, 2003). Lower part of the HKS-D magnet and installation of Q1 and Q2 were finished. From right to left, Q1, Q2 and the lower part of D can be seen. After the fiducialization, the upper part of the magnet will be assembled.

Table 1
Specification of the HKS

Configuration	Q-Q-D and horizontal 70° bend
Central momentum	1.2 GeV/c
Dispersion	4.7 cm/%
Momentum acceptance	±12.5% (1.05–1.35 GeV/c)
Momentum resolution ($\Delta p/p$)	2×10^{-4}
Solid angle	30 msr without the splitter
	16 msr with the splitter
Kaon detection angle	Horizontal: 7 degrees (1–13°)
Flight path length	10 m
Maximum magnetic field	1.6 T (normal conducting magnet)

2.2. Tilt method and the electron spectrometer (ENGE)

In the pilot $(\mathrm{e}, \mathrm{e}'\mathrm{K})$ hypernuclear experiment, E89-009, the electrons associated with bremsstrahlung dominated the background in the scattered electron spectrometer (Enge split-pole spectrometer). This ultra-high rate bremsstrahlung background limits the beam intensity and thus the hypernuclear yield. Therefore, it is essential to suppress the bremsstrahlung background.

We took particular note of the difference of the angular distributions between bremsstrahlung electrons and scattered electrons associated with the virtual photons which contribute to kaon production. Both of these scatterings have very forward distributions, however, electrons in the bremsstrahlung distribution are scattered more often near 0°.

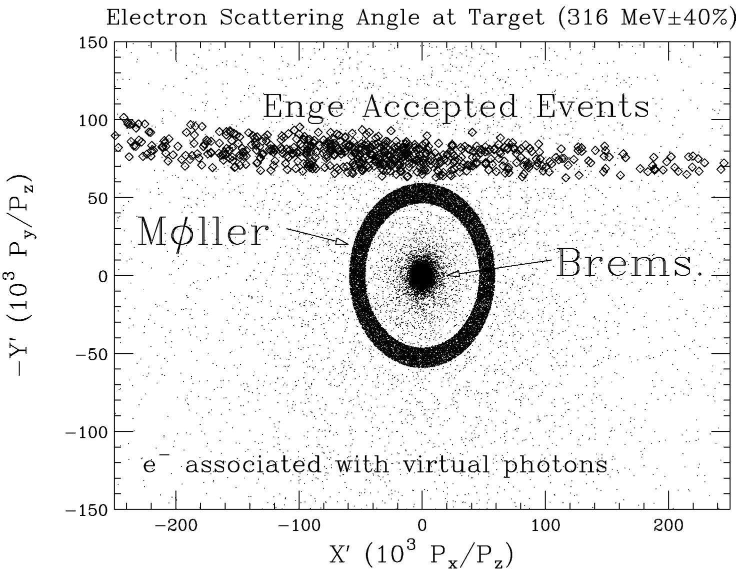

Fig. 3. The scattering angle of the electrons ($p = 316 \pm 40\%$ MeV/c) at the target calculated by the program RAYTRACE. The very forward bremsstrahlung electrons and Møller electron rings are observed. The acceptance of the 7.75° *tilted* ENGE spectrometer is located just outside of the Møller ring.

Therefore, we can avoid the extremely high rate electrons originating from bremsstrahlung and Møller scattering by tilting the ENGE spectrometer out of the bending plane defined by the splitter magnet (tilt method). However, increasing the tilt angle, the number of the accepted virtual photons decreases. We need to take following processes into account to optimize the tilt angle:

1. Virtual photon production associated with hypernuclear production,
2. Electron scattering associated with bremsstrahlung, and
3. Møller scattering electrons.

Fig. 3 shows the electron scattering angle distributions at the target. The electron distributions associated with bremsstrahlung, virtual photons and Møller scattering are plotted. Since the beam energy is fixed, the scattering angle and momentum for Møller scattering electrons have a one-to-one correspondence, and thus a ring shaped distribution results from Møller scattering within the momentum acceptance of the ENGE spectrometer.

Using the RAYTRACE optics code, the events which passed through the tilted ENGE spectrometer without hitting a pole or collimators were selected. Fig. 3 shows that the acceptance of the tilted ENGE spectrometer is located just outside of the Møller ring, and thus the *hyper*-forward bremsstrahlung background and Møller electrons are blocked while the electrons associated with virtual photons pass through the ENGE spectrometer.

Fig. 4 shows the tilt angle dependence of the rates for those processes. Defining the figure of merit as signal (virtual photon flux)/square root of the background (Møller plus bremsstrahlung), an ENGE tilt of about 8° is optimum. After detailed optimization of the

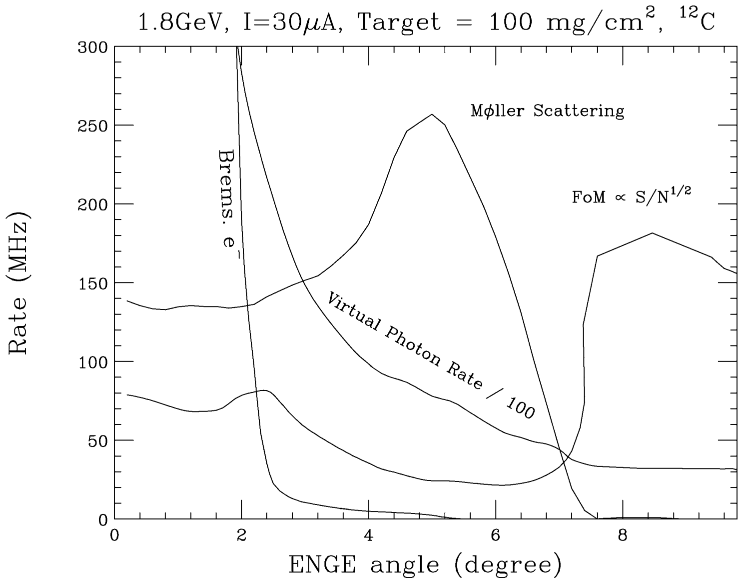

Fig. 4. ENGE tilt angle dependence of the expected rates. A beam current of 30 μA and carbon target of 100 mg/cm^2 are assumed. The figure of merit (FoM) is defined as $S/N^{1/2}$, where S is the virtual photon flux and N the sum of bremsstrahlung electrons and Møller scattering electrons. For viewing, the virtual photon flux is multiplied by 0.01 and FoM by an arbitrary factor.

tilt angle and vertical offset of the ENGE spectrometer from the splitter dispersion plane, we set the ENGE tilt angle at 7.75 degrees which selects the electron scattering angle of 60–100 mr (3.4–5.7°).

The tilt method reduces drastically ($\sim 10^{-4}$) the electron rate at the electron detectors. In the E89-009 experiment, the electron rate was over 200 MHz and it limits the beam intensity and the target thickness. The virtual photon yield is also reduced by the tilt method, however, it can be easily recovered by increasing the beam intensity and target thickness. The tilt method will reduce the electron rate from 200 MHz to a few MHz for a ^{12}C target, even with a target 5 times thicker and a beam $\sim$ 50 times more intense. It should be noted that the tilt method opens a chance to measure the hypernuclear spectra for the higher Z targets through the $(\mathrm{e}, \mathrm{e}'\mathrm{K}^+)$ reaction. The reduction of the electron background is essential for the heavier target, since the bremsstrahlung background becomes severer for higher Z targets.

3. Development of the detector packages

3.1. Kaon spectrometer

The HKS detector package is designed to identify K^+ from p, π^+, e^+ backgrounds with a total rate of a few MHz at maximum and to measure their momentum with an accuracy of 2×10^{-4} (FWHM). In order to realize the above requirements, the HKS de-

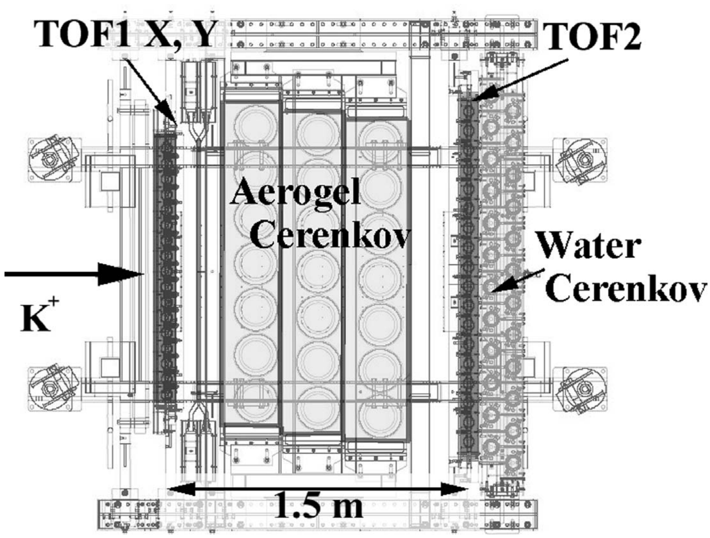

Fig. 5. Schematic figure of the HKS detector package. Two drift chambers (HDC) are placed with a space of 1 m just after the HKS-D magnet (far left, not drawn here). Downstream of the HDCs, a movable table, which is shown in this figure, is located. On the table, a start counter array for the time of flight measurement (HTOF1), aerogel Čerenkov counters (AČ), a stop counter array (HTOF2) and water Čerenkov counters (WČ) are placed. The flight path for TOF measurement is 1.5 m.

tector package consists of one pair of drift chambers (HDC), three planes of time-of-flight counters (HTOF), three planes of aerogel Čerenkov counters (AČ), and two planes of water Čerenkov counters (WČ). A schematic view of the HKS detector package is shown in Fig. 5.

The HDC is basically the same type of the drift chamber used for SOS (Short Orbit Spectrometer) in Hall C. The drift chambers, HDC1 and HDC2, are placed with 1 m spacing. Each consists of 6 layers ($xx'uu'vv'$; u and v planes are, respectively, tilted by 30° and −30°). The HTOF counters are designed to achieve a time resolution of 70 ps (rms) for 1.35 GeV/c K/π separation with a flight length of 1.5 m. Matsushita Electric's hydrophobic aerogel ($n = 1.050$) is used for the AČ to discriminate πs from Ks in the trigger level. In order to separate Ks and protons, water Čerenkov counters (WČ, $n = 1.33$) with a wave length shifter (amino-G-salt) are used.

In order to suppress the overkill of K^+ and to achieve high rejection power for π^+ and protons in the trigger level, the counters are segmented (TOF1 into 17, TOF2 into 18, AČ into 7 and WČ into 12). The first level trigger is made from the grouping of those segmented counters, as $\text{K trigger} = \sum_i \text{TOF1}_i \cdot \overline{\text{A\v{C}}_i} \cdot \text{TOF2}_i \cdot \text{W\v{C}}_i$ (subscript of i means the ith group of those segmented counters). The grouping is determined by a Monte Carlo simulation before the beamtime, but there may be a possibility to change the grouping or trigger scheme during the beamtime.

In order to minimize the effort to change the hard-wired triggers, we developed a special trigger module (Tohoku Universal Logic, TUL-8040) which uses a Field Programmable Gate Array chip (Altera APEX20K300EQC240-1X). The module can be programmed with

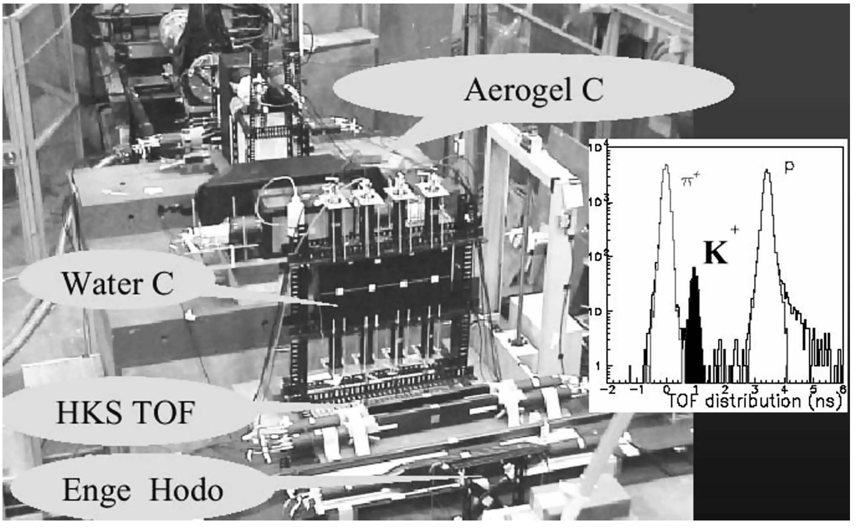

Fig. 6. Counter beam-test setup at the T1 beamline of the KEK 12 GeV proton synchrotron. Prototypes of the TOF counters, aerogel and water Čerenkov counters were placed on the beam line. K^+, π^+, and protons were separated with TOF information and e^+ are identified with CO_2 gas Čerenkov counter. With those particle ID information, aerogel and water Čerenkov counters' responses were investigated.

the VHDL language and the programmed logic can be checked with a circuit simulator. The grouping condition can be easily changed during the beamtime by up-loading the pre-tested programs.

3.2. Electron spectrometer

In the E89-009 experiment, the ENGE spectrometer is placed in the dispersion plane of the splitter magnet, and thus the position measurement gives enough momentum resolution without angular information. However, the tilt method distorts the original optical transport and it is essential to measure not only the hit positions of the particles but also their angles at the focal plane of the spectrometer. We developed a new honeycomb-cell structured drift chamber (EDC) with an effective area of 100 cm $\times$ 12 cm, in order to measure the position and angles of the scattered electrons with angles distributed from -5° to 40° at the exit of the ENGE spectrometer. The EDC has ten layers ($xx'uu'xx'vv'xx'$; u and v planes are, respectively, tilted by 30° and -30°) and all layers are installed in one chamber without windows to minimize multiple scattering. The chamber is designed to achieve a position resolution of 200 µm per plane and an angular resolution of 1.5 mrad for 300 MeV/c electrons.

The tilt method reduces the electron rate to a few MHz, but this is still high. Therefore, a plastic scintillation counter to measure electron timing must be highly segmented. Just behind the EDC, two layers of the plastic scintillation counter hodoscope (25 segmentation/layer) are placed for the timing measurement.

3.3. Detector beam test

Prototypes of aerogel and water Čerenkov counters, mass production version of the HKS TOF counters, ENGE hodoscopes are tested with 1.05–1.35 GeV/c unseparated p, K^+, π^+, e^+ beam at KEK-PS (T494, T500, T530), Tsukuba, Japan (Fig. 6). The EDC (honeycomb-cell drift chamber) is also beam tested at LNS, Tohoku University with e^+e^- pairs converted from the tagged photons.

The fabricated counters and EDC were checked to achieve the required performance with beams, and they have been transported to the JLab EEL building for the final tune.

4. Summary

A new improved hypernuclear spectroscopy up to medium heavy target with a newly developed High resolution Kaon Spectrometer (HKS) and a new configuration of the electron spectrometer (tilt method) is planned at the JLab Hall C. The energy resolution will be improved by a factor of two, and the hypernuclear yield and the signal to noise ratio will be improved by a factor of 50 and 10, respectively.

The HKS magnets fabrication and field map were finished in Japan and they were safely transported to JLab. Pre-assembly is now in progress at the test lab, JLab. Detector development and beam tests were completed. They are now under the final tune at the EEL building of JLab. The preparation for the experiment is in progress as planned. We will be ready for the beam in year 2004.

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