

Development of a Trigger System for Lambda Hypernuclear Spectroscopy at Jefferson Lab

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A next-generation Lambda hypernuclear mass spectroscopy experiment is planned at Jefferson Laboratory (JLab) using high-intensity electron beams. This experiment will cover a wide mass range from $A = 3$ to 208, enabling the investigation of Lambda-Nucleon charge symmetry breaking, ΛNN three-body force, and triaxial deformation etc. To perform the experiment, we are developing a data acquisition system that incorporates flash ADCs and VXS trigger processors (VTPs) where the trigger logic is controlled by FPGA.

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1. Introduction

Ground-state binding energies (0^+) for $A = 4$ iso-doublet hypernuclei (${}^4_{\Lambda}\text{H}$ and ${}^4_{\Lambda}\text{He}$) differ from each other as much as about 300 keV as shown in Figure 1. The large energy difference is evidence of charge symmetry breaking in the ΛN interaction (ΛN CSB). On the other hand, the energies of the first excited state (1^+) have no difference, which indicates the ΛN CSB is a spin-dependent interaction. The origin of the ΛN CSB is not clear and the large CSB is one of the mysteries in the strangeness nuclear physics. Investigation of other mass systems is important to pin down the origin of the ΛN CSB. There are some theoretical calculations [2–4] for larger mass numbers up to p -shell hypernuclei to study the ΛN CSB effect. New experimental data with higher accuracy to check the validities of theoretical calculations have been awaited.

2. Experimental setup

The $(e, e'K^+)$ reaction is used to produce Λ hypernuclei at Jefferson Laboratory (JLab), USA. Figure 2 shows the experimental setup in Hall C at JLab. High resolution spectrometers HES and HKS are used to measure momentum vectors of scattered electron (e') and K^+ , respectively. The reconstructed momentum vectors are used to deduce the mass of a hypernucleus. The Λ binding energy in the hypernucleus ${}^A_{\Lambda}\text{Z}$ is given by:

$$B_{\Lambda} = M_{\text{core}} + M_{\Lambda} - M_H$$

where M_{core} , M_{Λ} and M_H are the mass of the core nucleus, hyperon, and the hypernucleus, respectively. The binding energy resolution reaches 0.6 MeV (FWHM), due to the high momentum resolution of the HES and HKS spectrometers. HES and HKS have plastic scintillation detectors which detect any charged particles. The data are acquired when the signals are detected by the scintillation detectors of HES and HKS in coincidence (coincidence trigger). A coincidence rate of the “real” hypernuclear production events is only 0.003 count/sec under the condition that the luminosity is approximately $1.6 \times 10^{36} \text{ cm}^{-2}\text{s}^{-1}$ with ${}^{12}\text{C}$ target. However, a large number of background charged particles are expected in the HES and HKS spectrometers. The background rates for the experiment are estimated by a Monte-Carlo (MC) simulation that reproduces the particle rates in the previous hypernuclear experiment at JLab (JLab E05-115 Experiment) [5, 6]. The accidental coincidence rate is evaluated by using the counting rates in HES and HKS assuming signal widths are 30 and 200 ns for HKS and HES, respectively. As a result, the accidental coincidence rates are well below the capacity of our data acquisition system ($< 200 \text{ kHz}$).

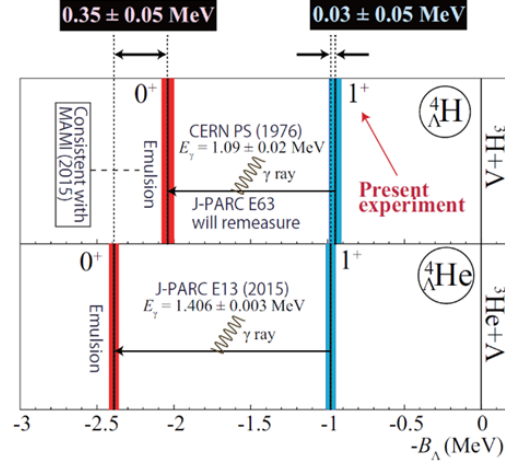


Figure 1: Binding energy difference for $A = 4$ iso-doublet hypernuclei [1].

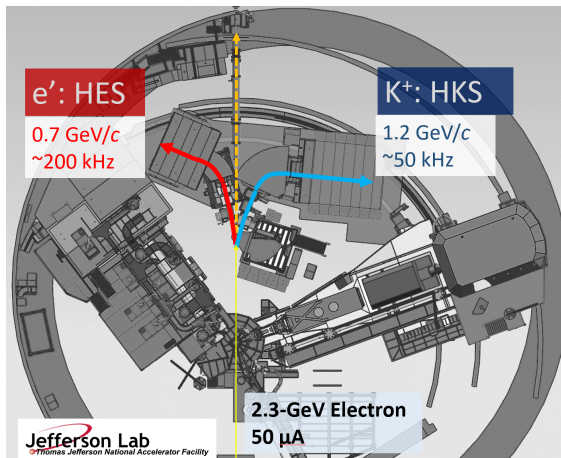


Figure 2: Layout of the hypernuclear experiment setup at JLab Hall C.

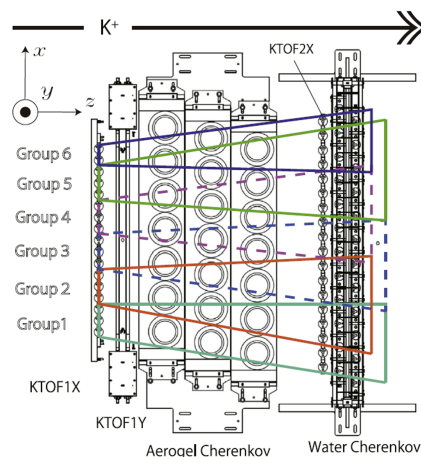


Figure 3: Schematic diagram of particle detectors located downstream of HKS [5]. Solid and dashed trapezoids represent an example of detector grouping for trigger logic.

3. Grouping trigger

The expected rate of the coincidence trigger can be handled by our DAQ system as shown in the previous section. However, we are planning to prepare an additional logic to eliminate unexpected background particles which are not generated in the target and whose tracks do not hence follow the pattern expected according to magnetic optics. Figure 3 shows a schematic of the HKS detectors positioned downstream of tracking chambers. There are three layers of plastic scintillation detectors (KTOF1X, 1Y, and 2X), and Cherenkov counters. By grouping some segments in each detector layer for constructing the trigger condition as shown in Figure 3, particles which are not generated in the target is eliminated (Grouping trigger (GT)). The trigger condition is processed by using a dedicated module called VTP (VXS Trigger Processor) [7]. VTP is equipped with an FPGA, enabling high-speed processing capable of handling high rates. VTP is being used for various experiments at JLab, and we are planning to use it for our trigger system. The trigger condition can be easily changed by modifying the source code remotely, even during the experiment.

4. Geant4 simulation for Grouping trigger in HKS

Three patterns of GTs (GT1—3) simulated using Geant4 MC simulations are presented here as examples. Charged particles generated at the target pass through the plastic scintillators with specific combination as shown in the upper panels of Figure 4. On the other hand, background particles may form a different pattern as shown in the lower panels in Figure 4. The distribution of background is arbitrary in the simulation because the unexpected background is unpredictable. Event selections by GT1—3 are represented as boxes in each panel. Survival ratios of the signal and the background events are evaluated and shown in Figure 4. We will prepare a basic framework for the grouping trigger before the experiment. The grouping trigger will be turned ON, and the condition will be modified and optimized during the experiment if necessary.

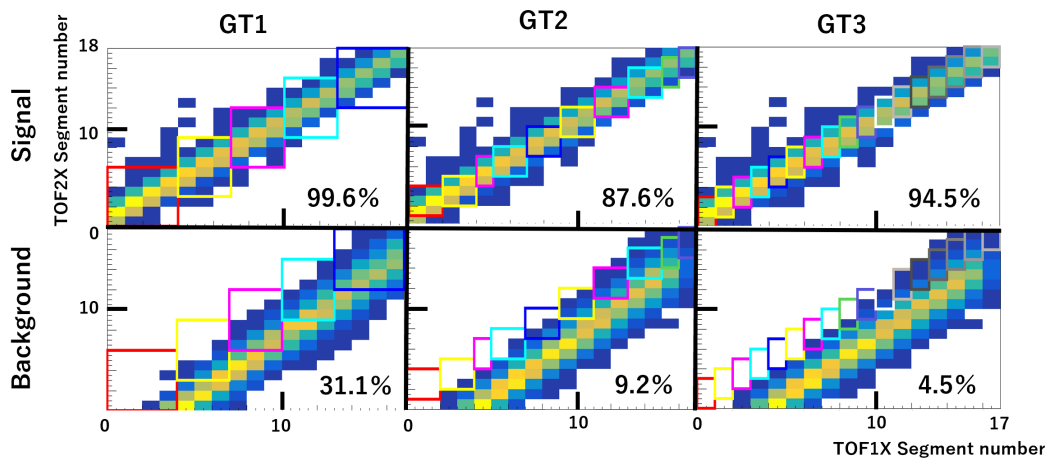


Figure 4: Hit-segments combination of KTOF1X and KTOF2X simulated by Geant4-MC simulation. Upper and lower panels are distributions for the signals and the artificial background, respectively. Groupings of GT1—3 are shown as boxed in left, middle, and right figure columns, respectively. Each number represents the survival ratios of signal and the assumed background events with GT1—3.

5. Conclusion

Λ hypernuclear mass spectroscopy will be carried out at JLab, aiming to investigate Λ N charge symmetry breaking, Λ NN three-body forces, and nuclear deformation. A dedicated data acquisition system incorporating flash ADCs and FPGA-based VTP modules is under development for the experiment. Grouping triggers (GT1—3) were studied using Geant4 MC simulations to evaluate their ability to suppress background events while maintaining signal efficiency. These simulations showed that appropriate trigger patterns can enhance event selection performance. A basic trigger framework will be prepared prior to the experiment, and the trigger conditions will be dynamically adjusted depending on actual background conditions. This flexible trigger strategy will contribute significantly to the success of the upcoming experiment, which are set to commence in 2027.

References

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