Hypernuclear Physics Programs via Electroproduction in Hall C at Jefferson Lab

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Hypernuclei with strangeness -1 have been intensively studied both theoretically and experimentally using hadronic probes and reactions, (K, π) and (π, K), for many years since the first discovery of such formation in the earlier nuclear emulsion and bubble chamber experiments. Many recent review papers exist on the status of hypernuclear physics, such as the recent one written by B.F. Gibson and Ed V. Hungerford[1)] in which one can find detailed discussion on all aspects of hypernuclear physics and more complete reference list. The unique feature of this field can be summarized, in general, into three categories: (1) Strong Interaction Involving Strangeness, (2) Weak Interaction with $\Delta S=-1$, and (3) Medium Modifications.

For strong interaction, it is commonly believed that a hyperon can be treated as an "impurity" to probe deep interior of the nuclear medium to explore fundamental issues such as the changes in size and shape due to the short range feature of YN interactions, limit of conventional nuclear model (shell or cluster) in solving for many body systems with new degree of freedom, spin dependent forces (spin-spin, spin-orbital, tensor), new symmetry and explicit QCD effect in nuclear media. Many of such issues are impossible or very difficult to be studied in the ordinary nuclear physics. The keys for success in this part of field includes good energy resolution and wide ranged spectroscopy.

Until now, many important issues are still unresolved or remained to be resolved in more consistent and satisfactory fashion, such as spin dependent forces. This is due to luck of high quality experimental facilities. Recent experiments at KEK[2)] using (π^+, K^+) reaction with a dedicated new SKS spectrometer have demonstrated the importance of improving the energy resolution. New structures were found as resolution improved only from 3 MeV to 2 MeV.

Electroproduction using the CEBAF high precision CW beam via an (e,e'K^+) reaction can provided an incompatible precision in the hypernuclear spectroscopy studies. The property of color blindness and gluon insensitive of the electroweak interaction makes the reaction easier to interpret. In addition to the natural spin transfer in the (virtual) photo-production the momentum transfer at extremely forward scattering directions for both the outgoing e' and K^+ is almost the same as that in the (π^+, K^+) reaction of about 350 MeV/c[3] for the production of Λ-hypernuclei. Therefore, this reaction can excite both the unnatural and natural parity high spin stretched states at the same time. It is possible for a direct and detailed study of the spin dependent forces which are generally believed to be small. It is possible to reach an energy resolution of about 200-300 keV. Significant physics can be learned with this precision in wide range of nuclear masses as mentioned above. Although the cross section is predicted to be more than two orders of magnitude lower than that by (π, K) reaction, the intensity and high duty factor of the CEBAF beam can compensate to reach a similar production rate. The spin structure selectivity makes the electroproduced hypernuclei complimentary to those produced by (K, π) and (π, K) reactions. A more complete analysis on hypernuclear spectra by different reactions is possible. Therefore, the programs at Jlab have potential to contribute significantly to the large advance of this field in the next decade or so. There have been many theoretical papers published in discussing this production (see some of the examples listed in Ref. 4-7).

The Hall C experiment, E89-009[8)], takes a low beam energy and luminosity approach to optimize the best reachable energy resolution and applies a zero degree scattered electron tagging technique to optimize the production. With the existing SOS spectrometer, the first phase experiment has chance to reach 600 keV resolution. Detailed discussion on physics motivations, experimental considerations, and the initial design of the experiment can be found in Ref. 8 - 10. The design of this experiment can allow a spectroscopy study extended to a heavier mass. With such resolution it is possible to observe directly the spin-orbital splittings at higher orbits in a heavy hypernuclear system, such as that proposed in experiment E97-008[11)]. This system can be easily upgraded to reach a resolution of about 200-300 keV level by replacing the SOS with a dedicated high resolution spectrometer, such as the NIKHEF QDQ and the newly designed SSOS spectrometers. In addition, the larger solid angle acceptance of these spectrometers (15 msr for the QDQ and 30 msr for the SSOS) will make the hypernuclear program wider ranged. Therefore, the incompatible high precision in the hypernuclear spectroscopy studies is the most obvious advantage for the future hypernuclear programs at Jlab, if such upgrade can be made.

For weak interaction, hypernuclear production provides a practical method to study the fundamental YN interaction. The hypernuclear nonmesonic weak decay channel, $YN \rightarrow NN$, provides a powerful tool to study both parity violation and conservation and exam the origin of the empirical $\Delta I=1/2$ rule[1)] which observed mainly from the kaon and hyperon mesonic decays. The question such as why the lifetime of hypernuclei seems not to decline significantly as the nonmesonic decay mode becomes dominant still remain yet to be answered. Many interesting physics issues associated with the strangeness weak decay remain to be further explored [1)] more precisely.

Study of this weak decay will be another main focus in this field in near future. Using CEBAF electron beam may not have clear advantages as using hadronic beam due to the high background radiation around target. However, with the low luminosity design of the Hall C hypernuclear experiment, some of the experiments may be possible to carry out. A precise production position and coincidence timing may turn out to be the major favor for Jlab programs with smaller systematic errors. For instance, by utilizing the unique beam characters of CEBAF beam, experiment such as E95-002 may provide direct lifetime measurement of heavy hypernuclear system with an accuracy of about 5% or better[12)].

Some properties, such as magnetic moment, of hypernuclei can be utilized to study the medium modification effect. By choosing the hypernuclei for which its magnetic moment is dominated by that of the free Λ, a measurement of its magnetic moment will provide information on some aspects of medium modifications. For this type of experiment, the precise beam position will help significantly for designing and carrying out such experiment.

Large solid angle acceptance spectrometer is essentially needed for weak decay and medium modification programs to increase significantly the production rate. The newly designed SSOS is certainly more favorable, even though high resolution is not needed for such experiments.

Electroproduction of hypernuclei using the CEBAF CW beam has a great opportunity for the successfulness and achievement in hypernuclear physics research. The Hall C experiment is ready to start and the data will be available soon which is complementary to those obtained at BNL, KEK, DAΦNE, and future JHF. A future update to push the resolution to the ultimate level and widen the physics topics in the strangeness -1 research is under pursuing.

References

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