Spin Observables in Kaon Electroproduction

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I. Introduction and Overview

The CEBAF accelerator at Jefferson Lab has proven to be a powerful tool for use in studying the electromagnetic production of hadronic systems containing a strange constituent quark. The electromagnetic probe only marginally disturbs the system being investigated, and is well understood [1-6]. Its use as a means to probe the internal structure of hadronic systems has been well documented. Among the most studied of these hadronic systems, currently, is the nucleon. The unique opportunities afforded by the use of polarized, high-current, high-duty-factor electron beams provides an even more powerful probe of the electromagnetic structure of hadronic systems; the study of the spin dependence of the electromagnetic production and weak decay of the hyperon, specifically the Λ-hyperon, becomes feasible.

An experiment to study the electroproduction of the Λ as a function of virtual photon momentum transfer, angle, and energy, using spin polarization observables in order to extract insights into its production and weak decay dynamics has already been approved at Jefferson Lab (E98-101; Spin Polarization in Kaon Electroproduction). The experiment aims to study the mechanism of polarization transfer in the reaction

$$\vec{e} + p \rightarrow e' + K + \vec{\Lambda}$$

The experiment requires only moderate momentum resolution and no specialized equipment other than that associated with the polarized beam. The data quality is expected to improve with higher electron beam energies, for higher Q^2 measurements. Additionally, at higher energies the increased virtual photon flux allows the experiment to be run at lower currents (and therefore high beam polarization). A polarized electron beam and an unpolarized cryogenic hydrogen target are required. The study uses the electron arm spectrometer and the hadron arm spectrometer to detect the scattered electron and the electroproduced kaon before it decays in flight, respectively. Additionally, the hadron arm will be used to detect the proton from the hyperon decay. The hadron arm used as a hyperon tagger, in general terms, will detect the protons resulting from the weak decays of the hyperons in

$$\vec{\Lambda} \rightarrow p + \pi$$

The hyperon is self-analyzing; its polarization will be determined by measuring the angular distribution and the momenta of the protons (from the hyperon decays) with respect to the hyperons' spin and momenta directions. Both the kaon and the hyperon in this measurement will be detected along the virtual photon direction (in the laboratory frame). Thus the hadron arm will serve the dual purpose of identifying the kaon electroproduction reaction as well as tagging the hyperon spin polarization vector. This is explained more carefully in the E98-101 proposal.

The reaction to be studied is given in the two equations shown in this paper. Once the momenta of the scattered electron and electroproduced kaon are measured, the hyperon momentum and energy are determined. Then, since the decay mechanism is well known, only the proton needs to be detected in the proposed measurement; the pion does not need to be detected. The hyperon momentum will be high enough so that the protons from the decay will lie in a rather tight cone centered on the hyperon momentum vector; the decay proton will be detected by the hyperon tagger (the hadron arm spectrometer) for all hyperon spin directions. At the same time, the hyperon momentum will be low enough so that reasonable angular resolution can be achieved for proton detection in the reaction. Time-of-flight information in the hadron arm will be used to identify the kaon and the proton and to determine their momenta.

II. Physics Motivation

A. Hyperon Spin Dynamics

It has been known for some time that Λ^0 hyperons can acquire a sizeable (induced) polarization even when produced using an unpolarized beam and target. This phenomenon is observed in both hadron and well as electromagnetic-induced hyperon production. There are several possible explanations of this effect. Most require the interference between low-lying baryon and meson resonances in the production process giving rise to rather large spin polarization. The polarization would be expected to vanish at high energies since, among other things, the contribution of several production channels with large multiplicities of final states make it unlikely to have coherent interference between spin nonflip and spin flip amplitudes which would lead to sizeable induced polarization. The observation of rather large induced polarization seen in hyperon production at high energies suggest a more complex picture of the process. More studies at high energies are needed to disentangle the physics. While there is recent data for polarization transfer in hadron-production of hyperons [10] and proposals to study induced polarization in photoproduction at Jefferson Lab, by contrast there is no data for polarization transfer from a polarized electron beam to a polarized hyperon in the electroproduction process.

The polarization transfer mechanism should give further insights into the role (if any) strange quarks play in hyperon structure; for example, no correlation is expected between incident electron polarization in associated production of kaons and hyperons, because the Λ^0 spin is thought to be carried entirely by its constituent *strange* quark, while the *ud* di-quark (in a spin and isospin singlet state) propogates unperturbed as a spectator in the interaction [10]. In that case, spin asymmetries related to the beam polarization are expected to vanish. If the polarization transfer from the electron to the hyperon is large, then this may signify that the *ud* di-quarks play a more prominent role in the recombination process than expected. The results of this study should shed light on this phenomena.

Additionally, it has been shown that the electroproduction of fast hyperons along the direction of the virtual photon can serve to illuminate the aptitude of the quarks to carry transverse polarization in the hyperon system [11]. The Λ is a uds isosinglet quark system. In the nonrelativistic quark model, if the up and down quark pair form a spin-zero core, the strange quark can carry most of the observed fraction of the spin of the hyperon. A measurement of the hyperon recoil polarization and the response functions $R_{TL'}$ and $R_{TT'}$ over a broad range of Q^2 will yield information on these dynamics.

B. Hyperon Electromagnetic Structure

There has been much recent interest in the study of the internal structure of baryons. Form factors are employed to describe the internal structure of hadronic systems [12-17]. Concurrently, nucleon form factors provide much needed, fundamental input for nucleon and nuclear structure models. The electric and magnetic form factors of neutrons and protons continue to be among the highest priority subjects in this field.

The marriage of these two subjects - strangeness electroproduction and nucleon form factors - results in a tantalizing new area for investigation, that of hyperon form factor measurements. Higher energy beams at Jefferson Lab (with polarization) can facilitate the extraction of information which is potentially sensitive to the electric and magnetic form factor of the Λ-hyperon at moderate to high momentum transfers. This information is fundamentally important in both nuclear and particle physics. The electroproduction of kaons with the associated production of hyperons (using polarization observables) is the most powerful means of extracting this information at large Q^2.

Presently, the only recoil polarization data in kaon electroproduction comes from the study of induced hyperon polarization [8-9,18]. (The kaon, being pseudoscalar, carries no spin polarization.) This study described in the E98-101 proposal and described here is the first proposed to study polarization transfer in the manner described in this proposal.

The earliest studies of the electromagnetic structure of the nucleons using moderate energy electromagnetic probes can be traced back to the work of Hofstadter and collaborators at Stanford [19]. It was shown that the electromagnetic probe interacts with the internal charge and current distribution of the nucleon - that is to say that the nucleons are not point objects, microscopically. The electromagnetic form factors are a measure of the deviation of these systems from pure point-like objects. The full momentum transfer dependence of these form factors cannot be calculated from first principles (quark and gluon degrees of freedom) over a large momentum transfer range. Experimental measurements combined with model calculations remain the only way to determine these quantities presently. Reasonable understanding of the internal structure of the baryons is necessary for progress in the field of intermediate energy nuclear and particle physics [20].

The most accurate experimental data that exists for nonzero momentum transfers is for the electric and magnetic form factors of the proton. Less precise data exist for the neutron. While these quantities have been measured reasonably well over a large momentum transfer region, there exists no data for the corresponding systems which contain a strange constituent quark, that is to say, hyperons. The polarization transfer from the electron to the hyperon in the reaction may be used to determine G_E^{Λ} and G_M^{Λ}, the Λ electric and magnetic form factors at nonzero momentum transfer.

III. REFERENCES

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