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The Space-like Kaon Electromagnetic Form Factor

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The electroproduction of kaons can potentially provide information about their space-like electromagnetic form factor at large momentum transfers. The aim of the recently completed Experiment E93-018 at the Thomas Jefferson National Accelerator Facility was to measure the elementary amplitudes in the associated production mechanism. Then, in principle, it should be possible to extract the kaon form factor at $Q^2 = 1.0$ GeV^2/c^2. This momentum transfer is more than an order of magnitude higher than previously acheived in kaon form factor measurements.

1. INTRODUCTION AND OVERVIEW

Electron scattering has proven to be an ideal tool for use in investigating nucleon and nuclear structure [1–6]. The electromagnetic interaction, the predominant interaction in electron scattering, is known and minimally disturbs the target compared to other interactions such as those using hadronic probes. The hadronic structure of the target nucleus can, consequently, be studied directly. The electron scattering variables, initial and final energy and scattering angle, can be varied in such ways as to vary the energy transfer and momentum transfer to the target. This brings out new and interesting features of nucleon and nuclear structure not directly attainable otherwise and allows measurement of the Fourier transform of the transition charge and current densities [1,3]. Then their detailed microscopic spatial structure can be studied. Additionally, varying the electron kinematics allows the separation of the various combinations of nuclear amplitudes contributing to the transition. An electron scattering program can be used to study various features of the nucleon systems, and of their mesonic, quark, and gluonic substructure [7].

Most of the nucleon and nuclear systems which make up our world are believed to be composed of up (u) and down (d) constituent quarks, and gluons. Those systems with strangeness have, in addition to u and d quarks, strange constituent quarks. The electromagnetic production of hadrons with constituent strangeness continues to be one of the most active investigations in the field of intermediate energy nuclear physics [8–16].

The K-meson, or kaon, is the lightest of the hadrons with constituent strangeness which is amenable to study, experimentally. The pion and, to an unknown extent, the kaon, contribute to the structure of the nucleon. Hence, precise knowledge of baryon structure requires a good understanding of meson form factors. Previous experimental studies of the

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kaon electromagnetic form factor, the measure of its internal electromagnetic structure, have been confined to low momentum transfers. The field's newest electron accelerator, the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF) is ideally suited for studies at high momentum transfers [7]. Experiment E93-018 at TJNAF [8], which has just recently completed data taking, aims to provide the first measure of the kaon electromagnetic form factor at $Q^2 \sim 1.0$ GeV^2/c^2. This momentum transfer would be more than an order of magnitude higher than previous experiments have achieved in attempting to extract the kaon electromagnetic form factor.

The experiment used the reaction

$$e + p \to e' + K^+ + \Lambda \tag{1}$$

$$e + p \to e' + K^+ + \Sigma^o \tag{2}$$

on the proton. (The incident electron energies were high enough so that Σ hyperons were produced in addition to Λ's.) The program was carried out by detecting, in coincidence, the scattered electron and the electroproduced kaon. The high duty factor of the CEBAF machine facilitate the implementation of coincidence experiments and measurement of final strange systems in coincidence with the scattered electrons in a systematic way where, because of the low duty factors of other high energy electron machines, only exploratory coincidence measurements were achievable before now.

Consider the general form of the electron scattering cross section for detection of a nucleon or meson in coincidence with the final scattered electron in the Born approximation. None of the spins, initial or final, are observed. The cross section can be written as a linear combination of four terms which completely characterize the dependence of the cross section on the nucleon or nuclear response.

$$\frac{1}{\Gamma_T}\frac{d^4\sigma}{dsdq^2dtd\phi} \equiv \frac{d\sigma}{dt}|_{K+} \tag{3}$$

$$= \sigma_U(Q^2, W, t) + \epsilon\sigma_L(Q^2, W, t) + \epsilon cos2\phi\sigma_T(Q^2, W, t) + \sqrt{2\epsilon(\epsilon+1)}cos\phi\sigma_I(Q^2, W, t) \tag{4}$$

where

$$\Gamma_T = \frac{\alpha(s - m^2)}{4(2\pi)^2 E_{1L}^2 m^2 |Q^2|(1-\epsilon)} \tag{5}$$

is related to the 'flux' of virtual photons, and

$$\epsilon = 1 + 2|\frac{k_L}{Q^2}|^2 tan^2\theta_e/2 \tag{6}$$

is the virtual photon polarization parameter.

The first term, σ_U, represents the cross section for kaon photoproduction by a virtual photon, unpolarized, with the photon spin vector in a plane transverse to the photon direction of motion. The term $\epsilon\sigma_L$ includes the cross section arising from longitudinally polarized photons where the virtual photon's spin vector is in the plane of its direction of motion. ϕ is the azimuthal angle between the electron scattering plane and the virtual photon-kaon-hyperon plane. When the kaon is produced at an out-of-plane angle ϕ (with respect to the electron scattering plane), the transverse photons can be polarized parallel or perpendicular to the K^+Y ($Y = \Lambda, \Sigma$) production plane. The term $\epsilon\sigma_P cos2\phi$ contains the cross section due to the interference between the transverse components of this virtual photon polarization. The last term in (4), $[2\epsilon(\epsilon+1)]^{1/2}\sigma_I cos\phi$ is proportional to the cross section due to the interference between the transverse and longitudinal photon polarizations. All the cross sections in (4) are functions of Q^2, W, and $\theta_{\gamma K^+}$ (or, in this case, t), where Q^2 is the four-momentum carried by the virtual photon, W is the total energy of the system in the center of mass of the reaction products, $\theta_{\gamma K^+}$ is the angle between the kaon and virtual photon and t is the square of the difference between the virtual photon four-momentum and the kaon four-momentum. $\theta_{\gamma K^+}$ and t yield essentially the same information in this study.

The attempt to extract the kaon electromagnetic form factor from this study assumes that the $K^+ - Y$ channel has a sizeable longitudinal cross section [17,18]. The main contribution to σ_L is expected from the exchange of a K^+-meson. So far there has been only a crude attempt [18] to separate σ_U and σ_L. Since the contributing terms $\sigma_U + \epsilon\sigma_L$ have not been separated (accurately) in a single experiment [19–24], there is no experimental evidence for σ_L dominating the $K^+\Lambda$ channel. E93-018 aims to provide the first accurate measurement of separated longitudinal and transverse cross sections. Analysis of the E93-018 data is underway currently.

The longitudinal cross section, σ_L should be sensitive to the kaon form factor [20]. Separation of the longitudinal contribution to the cross section and therefore the determination of the kaon form factor will depend upon the relative magnitudes of the first two terms in (4). (It would be more difficult to separate a very small contribution from a relatively very large contribution). The large uncertainty in the data which exists presently don't allow too stringent a prediction to be made on their relative contributions. Nevertheless, the trend of the data of [18] indicates that in the region of $Q^2 \leq 4\ GeV^2/c^2$, the unpolarized transverse contribution and the longitudinal polarized cross section are comparable in magnitude.

Single kaon electroproduction can then be used to determine the kaon form factor [20–26] for spacelike values of the photon mass squared ($q^2 < 0$). (Colliding beam experiments such as those planned at the DAPHNE facility measure the time-like kaon form factor via the reaction $e^+ + e^- \rightarrow K^+ + K^-$). This is similar to the work done to extract the pion form factor [17,27–33]. The analysis of the data to extract the form factor requires use of the Chew-Low extrapolation procedure [29]. The procedure assumes that the kaon pole, in this case, dominates the virtual photoproduction cross section for small t (close to t_{min}). If the pole in the denominator is multiplied out of the experimental cross sections, the resulting data should lie on a smooth curve which can be extrapolated to the pole position in t. This gives the residue of the pole. If the coupling constants involved are known beforehand, then the kaon form factor can, in principle, be determined [8,17,20,25,29,34].

Several models exist for describing the kaon form factor [25,35–38]. Among them are the Vector Meson Dominance Model [16] (the VMD model of this scattering assumes that the virtual photon converts into a vector meson before interacting with the target nucleon), a Relativistic Quark Model [25], and a Bethe Salpeter Model [36–38],to name a few. The Chew Low extrapolation technique proposed for the E93-018 data is believed to be the most model independent means of extracting the form factor.

2. EXPERIMENTAL PROCEDURE

The experimental program to determine, separately, the Q^2 and t dependences of the four terms of (4) due to virtual photoproduction of kaons was ideally suited for Hall C using the High Momentum Spectrometer (HMS) to detect the scattered electron and the Short Orbit Spectrometer (SOS) to detect, in coincidence with the HMS, the electroproduced kaon before its decay in flight [7,8].

The Rosenbluth separation needed to separate the transverse and longitudinal cross sections was implemented as follows: The SOS was centered on the virtual photon direction. This means that the interference terms of (4) (those terms proportional to $\cos\phi$ and $\cos 2\phi$) will average to zero since an average over the angle ϕ is effected by this arrangement. The remaining two terms, σ_U and $\epsilon\sigma_L$, are separated by varying ϵ, the virtual photon polarization parameter, between a high and low value. (By binning the data appropriately, offline, the interference terms can be measured versus t and W for all Q^2 settings as well.)

The detector stacks for the HMS and SOS are shown in Fig. 1. The detector stacks used standard focal plane instrumentation and is detailed in the CEBAF Conceptual Design Report [7]. There were drift chambers for charged particle tracking, Cherenkov detectors for particle identification, scintillator hodoscopes for fast timing, and Pb-glass shower counters for lepton calorimetry and an Aerogel Cherenkov counter in the hadron arm for kaon-pion separation.

The SOS is also a focusing spectrometer, but with a very short flight path (compared to the HMS). This short flight path enhances the detection of the short-lived kaons before their in-flight decay. It was advantageous, in the SOS, to use the time-of-flight differences between protons, pions, and kaons, in order to identify these charged particles (and therefore to separate them) at the lower spectrometer momentum settings. By optimizing the distance between the S1 and S3 scintillator arrays in the SOS detector hut, good charged particle separation was achieved. The proton-kaon time difference was large enough at all momenta that the time difference between them was resolved. For the higher momentum settings, judicious use of the Aerogel Cherenkov counter and some time-of-flight separation was adequate to give a clean kaon cut.

3. SUMMARY

Knowledge of the kaon electromagnetic form factor is needed for understanding baryon structure and for constraining models of quark interactions inside hadrons. The experimental study is aided enormously by the CEBAF accelerator at TJNAF for large space-like momentum transfers. Experiment E93-018 at TJNAF has recently completed taking data for kaon electroproduction where both the Λ and Σ hyperons were determined in the final state. Analysis of the data is currently underway. It is expected that the data will yield, for the first time, precisely separated longitudinal and transverse cross section data.

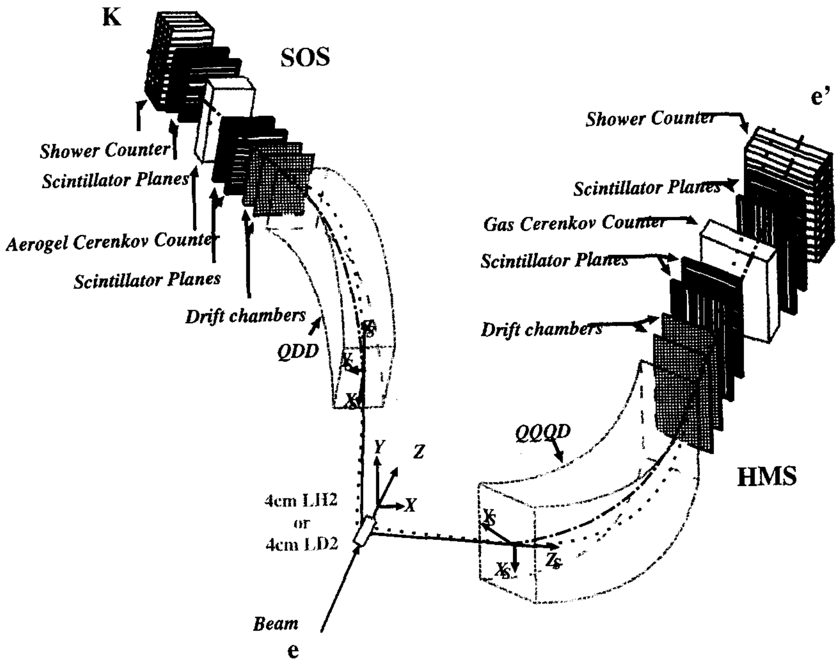

Figure 1. The detector stacks for the HMS and SOS spectrometers used in the coincidence experiment.

Consequently, extraction of the space-like kaon form factor at high momentum transfers should be possible.

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