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A. TITLE: Measurement of the Kaon Form Factor for $1.0\ \mathrm{GeV}^2/c^2 \leq Q^2 \leq 2.0\ \mathrm{GeV}^2/c^2$

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C. IS THIS PROPOSAL BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT?

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MEASUREMENT OF THE KAON FORM FACTOR FOR 1.0 $\mathrm{GeV}^2/\mathrm{c}^2 \leq Q^2 \leq 2.0\ \mathrm{GeV}^2/\mathrm{c}^2$

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ABSTRACT

This is a proposal to measure the kaon electromagnetic form factor up to a momentum transfer squared (Q^2 = -q^2) of 2.0 GeV^2/c^2. It is proposed that the measurement be made on hydrogen and deuterium. This form factor measurement will be performed by examining the cross section of kaon electroproduction, $p(e,e'K^+)\Lambda$, for several values of the virtual photon polarization, ϵ, and averaging over the azimuthal angle, ϕ, where ϕ is the angle between the electron scattering plane and the virtual photon-kaon plane. Present data for the kaon form factor extends only up to approximately $Q^2 = 0.3$ GeV^2/c^2. Thus this experiment would extend the kaon form factor measurement by more than a factor of 6 over the present range of Q^2. The experiment would be run in Hall C utilizing the HMS to detect scattered electrons and the SOS to detect short-lived kaons before their in-flight decay.

CEBAF EXPERIMENT MAJOR REQUIREMENTS

Total Beam Hours	80
Beam Energies (GeV)	2.6, 3.3, 3.7, 3.8, 4.0
Beam Type	Unpolarized
Beam Current	10 μA
Targets Needed	Liquid H_2, Liquid D_2
Power Deposition	$\leq$ 50 watts

SPECTROMETER REQUIREMENTS

	Electron Arm	Hadron Arm
Solid Angle	6 msr	9 msr
Momentum Acceptance	20%	40%
Momentum Resolution	$\leq 10^{-3}$	$\leq 10^{-3}$
Min Scatt Angle	14.5	14.4
Max Scatt Angle	51.8	23.1
Min Central Momentum	1.0 GeV	1.0 GeV
Max Central Momentum	2.0 GeV	2.0 GeV
Particle i.d. Required	π/e^-	π^+/K^+, p/K^+
Required Ratio	0.01	0.005

1. MOTIVATION

The electromagnetic production of strangeness is one of the forefront areas of research in intermediate energy nuclear physics [1-3]. The excellent beam and spectrometer qualities planned for the Continuous Electron Beam Accelerator Facility (CEBAF) are well suited to this type of study [4-5]. The dominant strangeness-production mechanism in this energy range (up to 4 GeV) is the electroproduction of kaons (K-mesons) along with the associated strange nucleons, the Λ and Σ nucleon, necessary to conserve strangeness in the reaction.

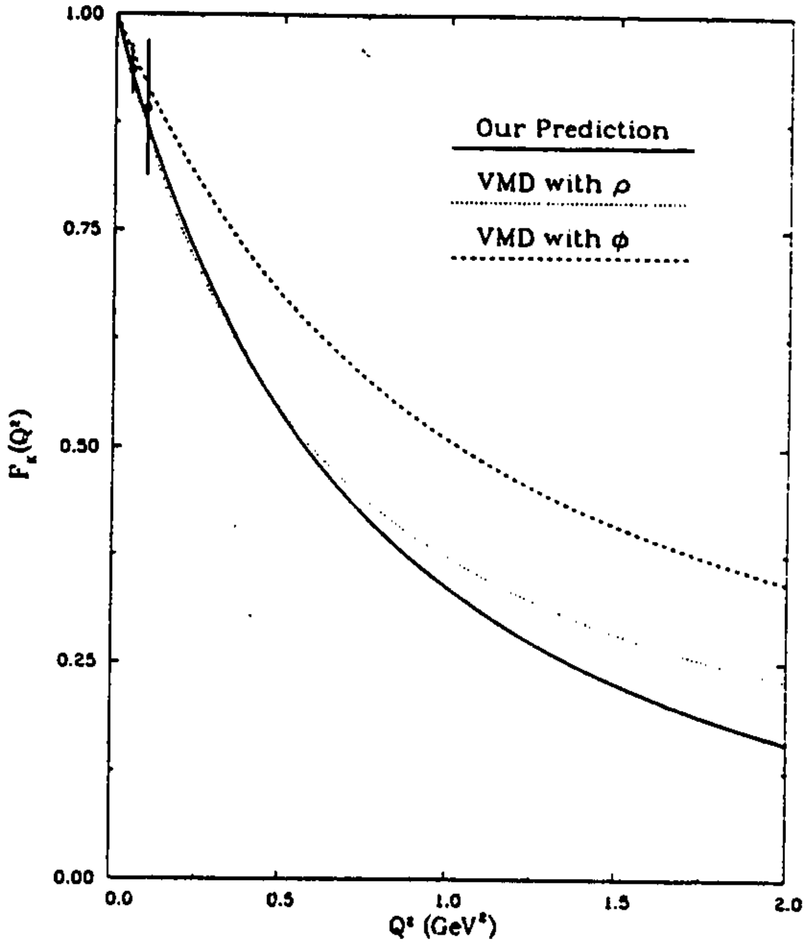

Fig. 1. Kaon electromagnetic form factor versus momentum transfer squared. The data are from reference [8] and [9]. The three curves shown are from calculations based upon several models as explained in reference [7].

One of the specific issues which must be addressed in this area of study is the kaon form factor, $F_{K^+}(Q^2)$, at moderate to high momentum transfers squared (Q^2), and the related quantity, the kaon charge radius which is obtained from the extraction to $Q^2 = 0$. From elementary considerations, the form factor is related to the charge distribution of the hadron, in this case the kaon. The differential cross section for electron scattering from a static, spinless, infinitely heavy charge distribution is given by [6]

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega})_{\mathrm{Mott}} |F(Q^2)|^2 \tag{1}$$

where all of the information about the charge distribution is given by the electromagnetic form factor $F(Q^2)$. For a point distribution, $F(Q^2) = 1$.

In spite of the importance of this work, very little research has been done on the kaon form factor measurement at the region of Q^2 of interest in this proposal. A very striking example of this is indicated in fig. 1. The figure, from reference [7], compares a calculation of the kaon form factor from a QCD-inspired model with a vector meson dominance (VDM) model calculation. The VDM essentials may be understood as follows. For an electromagnetic interaction between an electron and a hadron, a virtual space-like photon ($Q^2 < 0$) is exchanged as shown in fig. 2. In the VDM, the virtual photon converts to a neutral vector meson first and then couples to the hadron as shown. In the simplest form, the VDM asserts that the ρ^o meson is exchanged as indicated [6]. The form factor calculated in this model is given by

$$F_{K^+}(Q^2) = (1 + Q^2/m_v^2)^{-1} \tag{2}$$

where m_v is the neutral vector meson mass. The curves shown in fig. 1 indicate the sensitivity of the calculation upon the vector meson mass. A 5% measurement out to a Q^2 of 2 GeV^2/c^2 would distinguish between the two possibilities considered in this analysis from reference [7].

One of the most exciting issues which can be addressed with this proposed kaon form factor measurement in this momentum transfer range is a signature for the presence of quark degrees of freedom in hadrons. This requires a prediction based upon a quark model of the hadron which yields results measurably different from those based upon a meson description such as the VDM. The authors of reference [7] have made a calculation of the kaon form factor using a relativistic quark model of open flavored pseudoscalar mesons. The open flavor meson state $|M\rangle$ is represented by

$$|M\rangle = \psi^M_{Qq} |Qq\rangle. \tag{3}$$

In equation (3), $|Qq\rangle$ is the quark wavefunction for the heavy quark (in this case the strange antiquark) and the light quark (the up quark in this case) for the K^+-meson. ψ^M_{Qq} is the model wave function, a product of a light-cone harmonic oscillator wave function and a light-cone spin wave function. The prediction of this quark model calculation of the kaon form factor is indicated by the solid line of fig. 1. **The distinct difference between the quark model and the VDM predictions can be tested with this proposed experiment.**

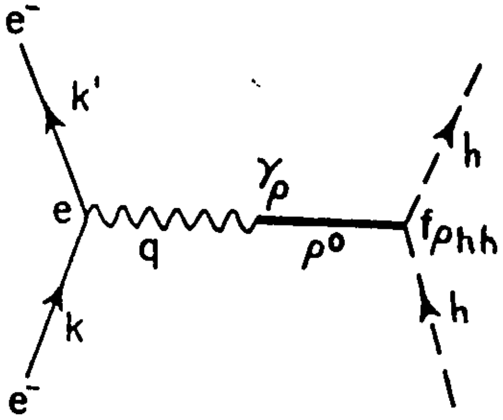

Fig. 2. The Vector Dominance Model involves the conversion of the virtual photon (with $q^2 < 0$) in electromagnetic scattering into a neutral vector meson before coupling to the hadron.

2. THEORETICAL DISCUSSION

The experiment will observe the reaction [10-12]

$$e^- + p \rightarrow e^- + K^+ + \Lambda \tag{4}$$

in hydrogen and deuterium nuclei. It will be carried out at electron incident energies above the threshold for Σ production, thus allowing, in addition to reaction (1), the reactions

$$e^- + n \rightarrow e^- + K^+ + \Sigma^- \tag{5}$$

and

$$e^- + p \rightarrow e^- + K^+ + \Sigma^o \tag{6}$$

in deuterium.

This study is similar to pion charge form factor investigations for which much work has been done and extensive data exists [13-17]. To first order in QED, the reaction (1) proceeds by one-photon exchange. Thus it is usual to treat the reaction (1) as a virtual photoproduction process:

$$\gamma_v + p \rightarrow K^+ + \Lambda \tag{7}$$

The electroproduction cross section for

$$p(e,e'K^+)\Lambda \tag{8}$$

in the center of mass frame, may be expressed as [13-17]

$$\frac{d\sigma}{d\Omega_K^* dM_\Lambda^2} = \frac{d\sigma_U}{d\Omega_K^* dM_\Lambda^2} + \epsilon\frac{d\sigma_L}{d\Omega_K^* dM_\Lambda^2} + \epsilon\frac{d\sigma_P}{d\Omega_K^* dM_\Lambda^2}\cos 2\phi +$$

$$+[\frac{\epsilon(\epsilon+1)}{2}]^{1/2}\frac{d\sigma_I}{d\Omega_K^* dM_\Lambda^2}\cos\phi \tag{9'}$$

which may be written for clarity as

$$= A + \epsilon B + \epsilon C\cos 2\phi + [\frac{\epsilon(\epsilon+1)}{2}]^{1/2} D\cos\phi. \tag{9}$$

The first term, A, represents the cross section due to unpolarized transverse photons. The term ϵB arises from longitudinally polarized photons while the terms involving ϕ are contributions from the interference between transverse amplitudes and scaler-transverse interference, respectively. ϕ is the azimuthal angle between the electron scattering plane and the virtual photon-kaon plane and ϵ is the photon polarization parameter:

$$\epsilon^{-1} = 1 + 2(1 + \frac{\nu^2}{Q^2})\tan^2(\theta_{e'}/2). \tag{10}$$

A schematic diagram showing the laboratory kinematical variables and reaction planes is presented in fig. 3.

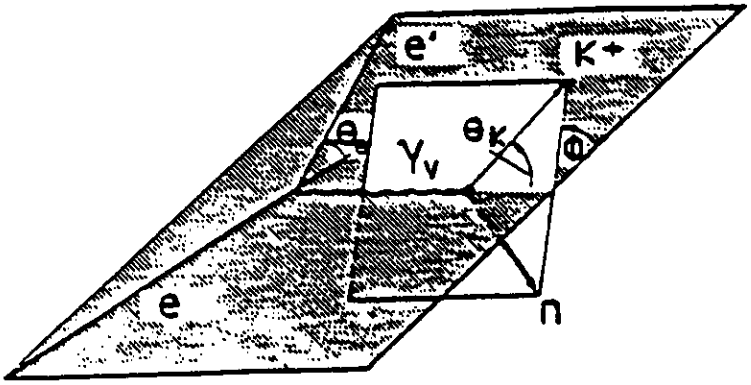

Fig. (3). The laboratory kinematical variables and reaction planes for the coincidence experiment.

It is the longitudinal amplitude which is directly proportional to the kaon electromagnetic form factor and which is to be determined [18]. Therefore, the longitudinally polarized term, ϵB of equation (9), is of interest and must be separated from the other three terms. This is achieved by varying the virtual photon polarization, ϵ, and simultaneously averaging over all ϕ , that is, by a Rosenbluth separation. It is proposed to do this at Q^2 up to 2 GeV^2/c^2. The kinematical parameters for the separation are shown in Table I.

Separation of the longitudinal contribution to the cross section and therefore the measurement of the kaon form factor will depend upon the relative magnitudes of the four terms in eqn (9). Each of the terms has a small momentum transfer squared (Q^2) and angular (θ_{K^+}) dependence [17,19]. These separate contributions have not been measured accurately in the momentum transfer region of interest here; estimates, however, can be readily made of their relative sizes [19]. A plot of B/A of eqn (9) is presented in fig. (4). This is the ratio of the magnitudes of the longitudinal polarized term to the unpolarized transverse term. The large uncertainty (which would be reduced in this experiment) don't allow too stringent a prediction to be made on their relative contributions. Nevertheless, the trend of the data indicates that in the region of $Q^2 \leq 4$ GeV^2/c^2, the unpolarized

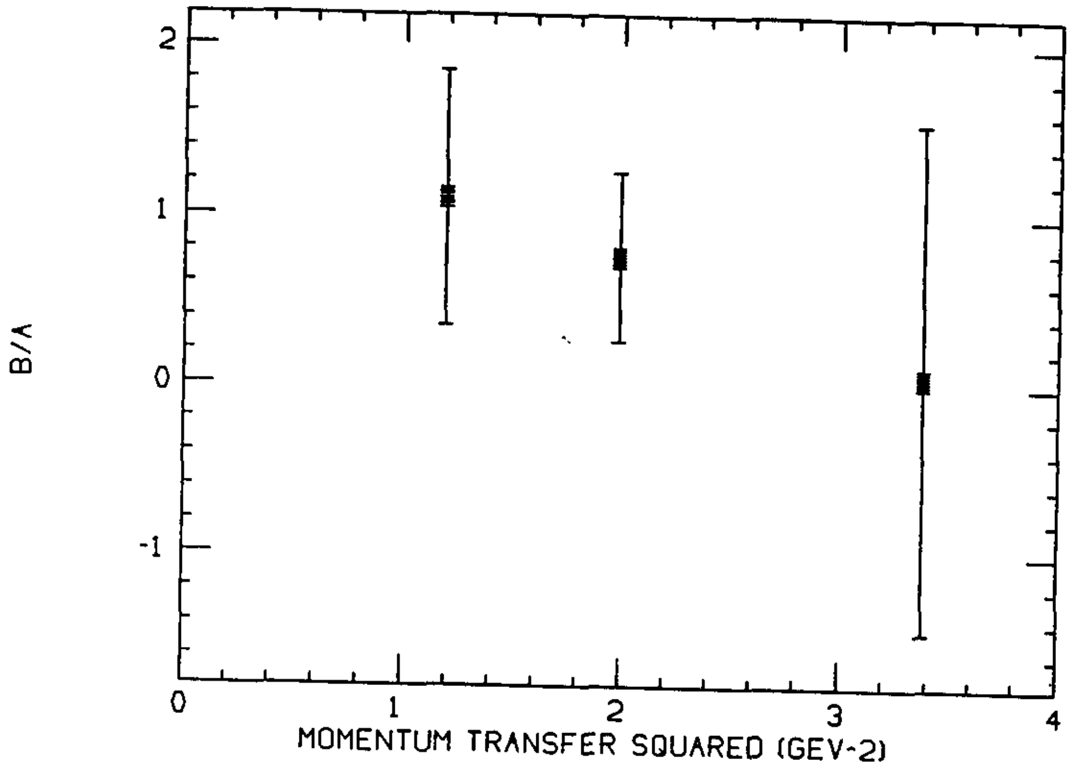

Fig. (4). The ratio of the contribution to the cross section (eqn 9) from the longitudinal polarized term and the transverse unpolarized terms (A and B terms, respectively). This is from the work of reference [19].

transverse contribution and that of the longitudinal polarized term are comparable. Using the results of the work on coincident electroproduction of pions (where the kinematics are very similar to those of this proposed experiment), an estimate can be made of the other terms as well. In the angular and momentum transfer squared region of this proposed experiment, the contributions from the transverse polarized and interference terms (C and D terms respectively of eqn (9)) are comparable in magnitude and opposite in sign to the unpolarized and longitudinal terms (A and B terms, respectively, of eqn (9)) [17]. Along the virtual photon direction (which is where the SOS spectrometer central axis will be positioned), the interference terms are zero. Due to the finite acceptance of the SOS, these terms will average to zero. Thus the uniformity in relative magnitudes of the terms of eqn (9) should facilitate separation of the various contributions. It will be possible, therefore, to perform the required Rosenbluth separation and single out the term in equation (9) due to longitudinally polarized photons in this experiment in a straightforward way.

TABLE I
Kinematical Parameters for σ_L/σ_U Separation

Q^2 (GeV^2/c^2)	E_e (GeV)	E'_e (GeV)	θ_e	θ_γ	W (GeV)	ϵ
1.00	2.6	0.8	41.6°	14.4°	1.81	0.43
1.00	3.8	2.1	20.5°	20.6°	1.81	0.79
1.50	2.6	0.8	51.8°	16.0°	1.66	0.40
1.50	3.7	1.9	26.5°	23.1°	1.66	0.74
1.99	3.3	0.8	50.7°	12.7°	1.89	0.35
1.99	4.0	1.9	29.6°	21.8°	1.68	0.69

3. EXPERIMENTAL OVERVIEW

The experiment will use the High Momentum Spectrometer (HMS) and the Short Orbit Spectrometer (SOS) of Hall C. The HMS will detect the scattered electrons while the SOS with its short flight path will be necessary to detect the short-lived kaons before their decay in flight. The Rosenbluth separation described in section 2 of this proposal will be implemented as follows: The SOS spectrometer will be centered on the virtual photon direction. This means that the interference terms of equation (9) (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 2 terms, A and ϵB, are separated by varying ϵ, the virtual photon polarization parameter, between a high and low value. The kinematics for this separation are shown in Table I. CEBAF will provide the liquid hydrogen and deuterium targets which will also be ready at startup.

The HMS Detector and Background Estimates

The detector stack for the HMS detector is shown in fig. 5. The detector stack uses standard focal plane instrumentation and is detailed in the CEBAF Conceptual Design Report [4]. There will be drift chambers for charged particle tracking, a gas Cherenkov detector for particle identification, scintillator hodoscopes for fast timing, and Pb-glass shower counters for calorimetry. Each of these components has already been approved for construction and will be ready for use at the start of Hall C operation.

Charged particle trajectories will be measured using 2 multiwire drift chambers each having XYUVY'X' planes with the U and V stereo planes at 15° with respect to the X and X' planes. The X'(Y') planes are offset by 1/2 cell from the X(Y) planes. Thus there will be 12 multiwire planes before the scintillator hodoscopes or Cherenkov detector. The drift chambers will have cell sizes of 10 mm × 8 mm.

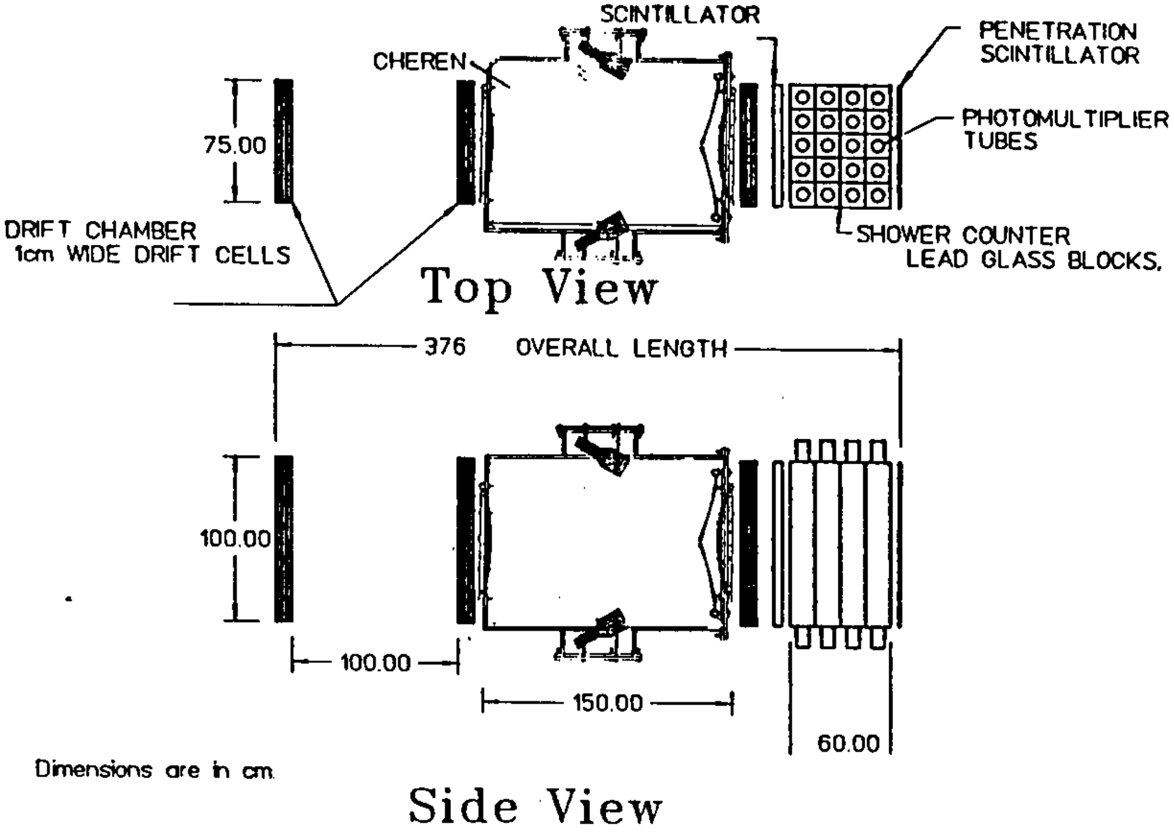

Fig. (5). The detector stack proposed for the HMS spectrometer used in the coincidence experiment. This arrangement is the same as described in the CEBAF Conceptual Design Report.

The scintillator hodoscopes will be used for fast timing while the shower counters will be used for charged particle energy determination. The gas Cherenkov detector will be used for π-e and p-e discrimination. Additionally, there should be some separation of charged particles from the Pb:glass shower counters. It is expected that pion-electron and proton-electron separations of 500/1 will be sufficient to reduce the backgrounds to acceptable levels [4]. It is expected that angular resolutions of less than 4 mr are attainable with both the HMS and SOS detectors utilizing the drift chamber designs proposed [20]. With momentum resolutions of $\leq 10^{-3}$ in each spectrometer, the uncertainties due to angle and momentum measurements should be negligible when compared with statistical uncertainties for a measurement with 5% accuracy.

TABLE II
Time-of-Flight Differences for SOS Spectrometer*

Q^2 (GeV^2/c^2)	ϵ	P_K (GeV)	$\Delta t(K-e)$	$\Delta t(K-\pi)$	$\Delta t(K-p)$
1.00	0.43	1.3	2.0	1.9	5.2
1.00	0.79	1.3	2.0	1.9	5.2
1.50	0.40	1.02	3.3	3.0	8.2
1.50	0.74	1.01	3.3	3.0	8.2
1.99	0.35	1.89	1.0	1.0	2.6
1.99	0.69	1.23	2.6	2.4	6.0

* Time in ns.

The SOS Detector and Background Estimates

The Short Orbit Spectrometer (SOS) will be employed as the hadron arm for this experiment. A sketch of the proposed detector stack is shown in fig. (6). The proposed SOS detector package consists of 2 sets of planar drift chambers, scintillator hodoscopes, a third drift chamber set followed by a second array of scintillators, an Aerogel Cherenkov counter, and finally a third set of XY scintillator planes. It is advantageous, in the SOS, to use the time-of-flight differences between protons, pions, kaons, and electrons to identifiy these charged particles (and therefore to separate them) at the lower spectrometer momentum settings. By maximizing the distance between the S1 and S3 scintillator arrays in the SOS detector hut, charged particle separation may be achieved. The time of flight differences for the various charged particles are listed in Table II. The proton-kaon time difference is large enough at all momenta that the time difference may be resolved. For the higher momentum settings, judicious use of the Aerogel Cherenkov counter and some time-of-flight separation should adequately give a clean kaon signal. It is estimated that using this system, a pion rejection (the most insidious problem) of approximately 10^3 is achievable. This is expected to be adequate for this experiment [21].

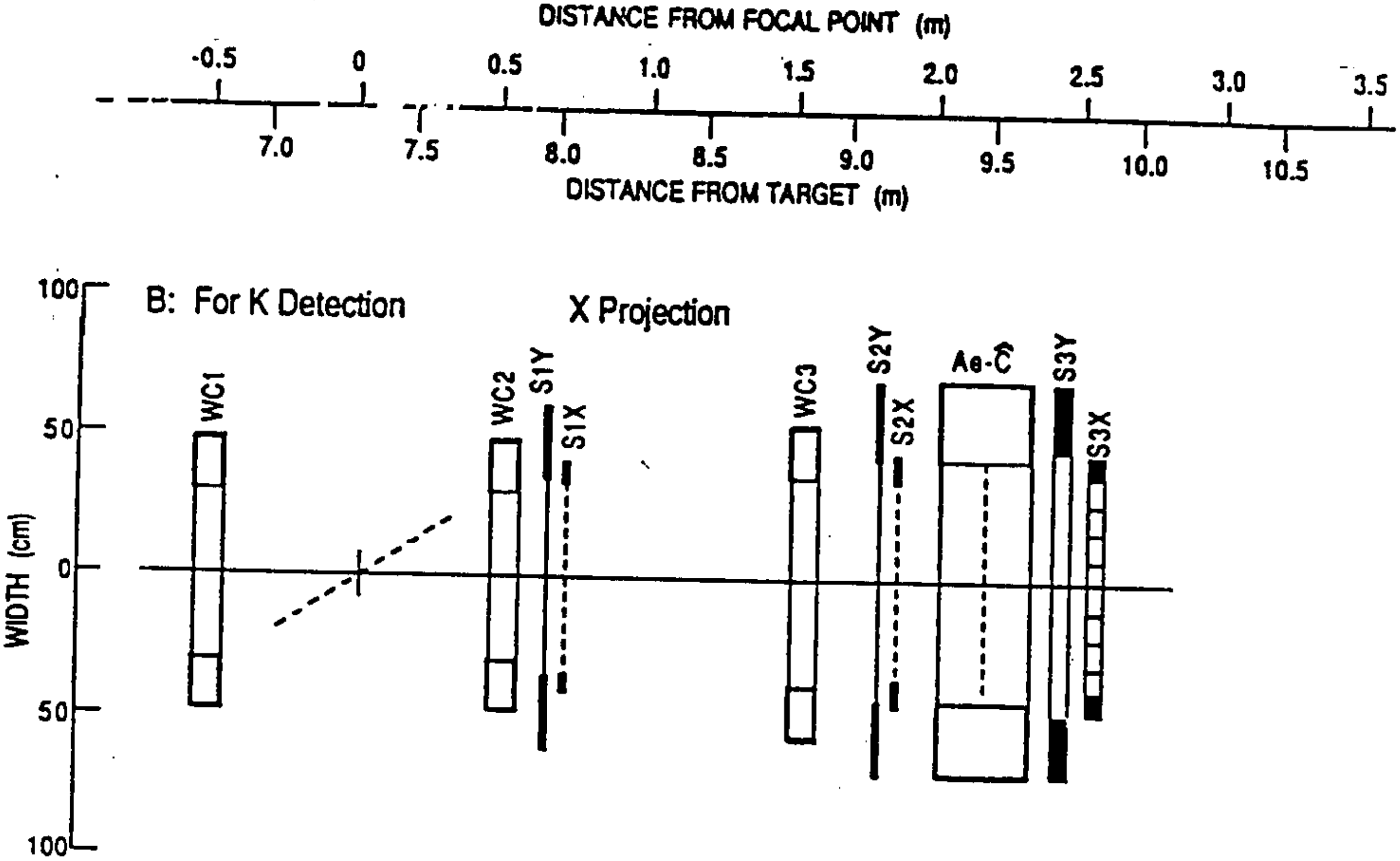

Fig. (6). The detector stack proposed for the SOS spectrometer used in the coincidence experiment. This compliment of subsystems is the same as described in the CEBAF Conceptual Design Report.

The momentum of a charged particle will be determined by reconstructing its trajectory through the dipole (bending) magnet while the production angles are then obtained by tracing the trajectory through the quadrupole (focussing) magnets back to the target position. The maximum momentum acceptance is 20% (40%) while the solid angle is 6.4 msr (9 msr) for the HMS (SOS) spectrometer. This technique will be used for both arms of the experiment.

4. RATES AND BEAM TIME REQUEST

An estimate of the singles rates, R, in each of the spectrometers separately may be obtained from

$$R = n_i \cdot n_t \cdot t \cdot \frac{d\sigma}{d\Omega} \cdot \Delta\Omega \tag{11}$$

where n_i is the number of incident particles per second on a target of thickness t and target density n_t. $d\sigma/d\Omega$ is the scattering cross section and $\Delta\Omega$ is the spectrometer solid angle. In the electron arm, the Mott cross section formula for $d\sigma/d\Omega$ is used in calculating the rates. The rates are shown in Tables III and IV. Preliminary results from the prototype drift chamber studies using the drift cells described in reference [22] indicate that these rates will cause no difficulty for the charged particle tracking. For the hadron arm, cross sections are estimated using the results from reference [23].

TABLE III
HMS Singles Counting Rates*

Q^2 (GeV^2/c^2)	ϵ	$d\sigma/d\Omega$ (ub/sr)	Rate (kHz)
1.00	0.43	0.04	3
1.00	0.79	0.35	31
1.50	0.40	0.02	2
1.50	0.74	0.13	11
1.99	0.35	0.01	1
1.99	0.69	0.07	6

* 10 μA electron beam, liquid hydrogen target.

The coincidence rate, R_{coinc}, for the HMS and SOS used in this experiment is estimated using the formula [23]

$$R_{coinc} = \frac{i}{e} \cdot \frac{\rho t N_o}{A} \cdot \epsilon_D \cdot \frac{d^3\sigma}{dE_e d\Omega_e d\Omega_k} \cdot \Delta E_e \Delta\Omega_e \Delta\Omega_k \tag{12}$$

where $\Delta\Omega$ is the solid angle of the spectrometer, ϵ_D is the detection effeciency, i is the beam current, N_o is Avogadro's number, e is the electron charge, t is the target thickness of mass number A and density ρ. For the HMS spectrometer, $\Delta E/E$ will be about 20%. For a hydrogen target, 100 nb cross section [24-25] for kaon electroproduction, and 10 μA of beam, a coincidence rate of about 0.5 counts per second is expected, for example.

TABLE IV
SOS Singles Counting Rates*

Q^2 (GeV^2/c^2)	$d\sigma/d\Omega$ (ub/sr)	Rate (kHz)
1.00	0.10	12
1.50	0.05	6
1.99	0.03	4

* 10 μA electron beam, liquid hydrogen target.

An estimate of the number of accidental to true coincidences A/T is obtained from

$$\frac{A}{T} = \frac{\tau R_e R_k}{F_D \; R_{coinc}} \tag{13}$$

where F_D is 1 for the CEBAF facility and the resolving time, τ, is taken to be 2.5 ns. Although A/D could be reduced somewhat by lowering the beam current (at the expense of counting rates), this ratio should allow a 5% measurement without difficulty.

TABLE V
Coincidence Rates*

Q^2 (GeV^2/c^2)	R_{Coinc}	Acc./True	Time (Hours)
1.00	0.50	1.02	10
1.50	0.50	0.20	10
1.99	0.50	0.07	10

* 2.5 ns resolving time.

A measurement at the momentum transfer proposed here with the statistics required will require approximately 80 hours of running. This is summarized in Table VI.

TABLE VI
Beam Time Request

	Time (Hours)
Data Acquisition	30
Setup and Checkout	24
Angle Changes	10
Contingency (25%)	16
TOTAL	80

5. MANPOWER AND COMMITTMENTS

There is a large committment on the part of the collaborators on this proposal. Each institution listed and the members from these institutions have responsibility for delivering and maintaining a part of the detector stack for the HMS and SOS spectrometers. Additionally, many of the collaborators have interest in other Hall C experiments utilizing these two spectrometers, whether in singles mode or coincidence experiments such as this one. Additionally, there will be a large number of graduate students from these institutions taking part in the experiment. It is expected that some fraction of these students will use this experiment towards their Ph. D. degrees. Although none of the names listed as collaborators are students, some students already are working on parts of this project.

One of the institutions, Hampton University, has just recently been awarded a $5 million grant from the NSF for nuclear and high energy physics research. A major part of this funding is for CEBAF-related work and would go towards this experimental study (outlined in this proposal). This includes both equipment and personnel. The grant is for a 5 year period with the possibility for renewal for an additional 8 years afterwards.

Additionally, Hampton University has been approved to offer the Ph. D. degree in physics beginning in the fall of 1992. This project would serve exceptionally well as a thesis experiment for students in the program. Presently, the Spokesperson for this experiment has a DOE grant for CEBAF related work. Two graduate students are working on the project. A postdoctoral researcher is expected to join the work before the end of 1991 at Hampton University. Other students and postdocts are expected to join from the collaborating institutions as well.

6. FUTURE PLANS AND SUMMARY

The plans for the immediate future is to extend the kaon form factor measurement up to 3 GeV^2/c^2, in line with the increase in beam energy at CEBAF. Additionally, plans are to investigate the kaon form factor measurement in a ^{56}Fe target in order to compare with the measurement in deuterium.

To conclude, one of the most demanding and challenging areas of research in intermediate energy nuclear physics is the study of the behaviour of nucleons and mesons in the nuclear medium. This is precisely the area where the Continuous Electron Beam Accelerator Facility (CEBAF) beam should allow excellent and perhaps unparalleled success. At the same time, one of the most intriguing subjects of study in intermediate energy physics is that of strangeness production and the behaviour of strange nucleons and mesons in the nuclear medium. Both these regimes would be addressed by this study.

This initial measurements, as outlined in this proposal, aims to effect a Rosenbluth separation of the various components of the cross section for kaon electroproduction, thereby separating out the longitudinal contribution which is directly proportional to the kaon form factor. The measurement is to be made on liquid hydrogen and deuterium targets in the range $1.0 \leq Q^2 \leq 2.0$ GeV^2/c^2. This would extend the kaon form factor measurement into a regime where none have been made adequately before. It will allow a comparison of the kaon form factor between conventional meson exchange models and QCD-inspired (quark) models.

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