CLAS E1 RUN GROUP JEOPARDY PROPOSAL

Experiment Spokespersons

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Contents

Abstract

This document serves as the framework to the Jefferson Laboratory PAC committee for the jeopardy defense of the E1 run group in Hall B. The E1 run group comprises 17 individual experiments using common run conditions to study a variety of reactions, including single pion and eta production, two pion production, open-strangeness production, hyperon excitation, vector meson production, and others. The primary goal of the program is to better understand nucleon structure in the transition region from small to large distances where perturbative methods of QCD are not applicable. The experiments are intended to probe fundamental symmetry properties related to the internal structure of baryons.

The experiments of the E1 run group encompass a large number of individual experiments, each seeking to understand some particular aspect of baryonic structure and dynamics. However, our approach in this first-ever Hall B jeopardy proposal will be to focus on four of our flagship analysis programs to detail the importance of the beam time to completion of our program. These major analysis programs focus on: low Q^2 single pion production to study the E2/M1 ratio for the $N - \Delta(1232)$ transition form factor, beam single spin asymmetries in single pion production that are very helpful in separating background and resonance amplitudes in the resonance region, the continuation of the search for so-called "missing resonances" decaying to multi-pion final states, and strangeness physics of ground and low-lying excited state hyperons.

The total beam time allocated by the PAC for the E1 run group is 122 beam days at energies ranging from 1.5 to 5 GeV, with both liquid hydrogen and deuterium as production targets. To date, 61 days of effective beam time, or 50% of the allocated total, have been used in three separate run periods over the past 3 years. An additional 30 days have been scheduled to run in the first part of 2002. We request that the PAC re-approve the remaining *30 days* of E1 beam time to allow us to complete our physics program.

The 30 days of beam time that we are seeking will be divided into running on both liquid hydrogen and deuterium targets. Our allocation of this beam time is divided into three parts. Ten days is requested at beam energies at and below 1.5 GeV on hydrogen for the low Q^2 single pion production experiments. Ten days are requested for running at 1.5 and 3.2 GeV with a deuterium target for completion of the isospin amplitude analysis of both the $\pi^+ n$ and $\pi^0 p$ data. Finally, ten days are requested for running at 3.2 GeV on hydrogen for the multi-pion and strangeness physics programs.

1 Overview

1.1 Introduction

The E1 run group comprises 17 individual experiments using common run conditions to study a variety of reactions, including single pion and eta production, two pion production, open-strangeness production, hyperon excitation, vector meson production, and others. Both unpolarized and polarized electron beams with energies from 1.5 to 5 GeV have been used with hydrogen and deuterium targets. A complete list of all experiments in the E1 run group is included in Appendix A.

The primary goal of the program is to better understand nucleon structure in the transition region from small to large distances where perturbative methods of QCD are not applicable. The physics analyses include precise measurements of the helicity structure of nucleon resonance transitions, searches for "missing" baryon resonances predicted by QCD-inspired quark models, the study of strangeness production mechanisms, and hyperon excitations. Since the measurements cover a range of Q^2 from 0.1 to 4 $(\mathrm{GeV/c})^2$, detailed information on nucleon structure is obtained over a range of distance scales from approximately 0.1 to 1 fm, spanning much of the range from quark asymptotic freedom to nuclear dimensions. This program will provide the experimental data needed to address questions such as "What are the relevant degrees of freedom to describe the nucleon at different distance scales?", and help to connect successful models such as the quark model, to the fundamentals of QCD.

1.2 Experiment Status

The total beam time allocated to the E1 run group is 122 beam days at energies ranging from 1.5 to 5 GeV, with liquid hydrogen and deuterium as production targets. A summary of our completed data runs is given in Table 1. To date, 61 days of effective beam time, or 50% of the allocated total, have been used, mostly on hydrogen targets and at lower beam energies. An additional 30 days of effective beam time have been scheduled to run in the first part of 2002. Thus this proposal is being provided to request re-approval of the final *30 days* of beam time previously approved by the PAC for allocation to the E1 run group in Hall B.

Our beam time has been accumulated in a total of three separate running periods, in 1997/1998 (E1A/E1B), 1999 (E1C), and 2000 (E1D), with electron beam energies of 1.5/1.6 GeV, 2.4/2.5 GeV, 3.1 GeV, and several energies from 4.0 - 4.8 GeV. The reason for the many different energy settings is due to the requirement of compatibility with high electron polarization in all experimental Halls. Data were taken with several different current settings for the main CLAS torus magnet, typically 1500 A, 2250 A, and 3375 A, dependent on the resolution and acceptance requirements of the individual experiments. The data have been collected with a loosely defined single electron trigger to keep nearly all events that contain an electron with energy above a pre-determined threshold that scattered into the active area of CLAS. This area is defined as the region covered by the combination of the drift chambers, the Cerenkov counters, and the electromagnetic calorimeters. With this trigger, off-line analysis is used to select events for the different experiments on the basis of the hadronic event topology in the final state.

Polarized electrons were available for most of the data acquired after 1998, with beam polarization ranging from 60 to 75%. For the lower beam energies, limitations of the data acquisition system limited the measurements to luminosities of 2-3$\times 10^{33}$ cm^{-2}sec^{-1}. For the higher-energy runs, luminosities of up to 10^{34} cm^{-2}s^{-1} were used. The total number of accumulated electron events now exceeds 1.5$\times 10^{9}$, with all possible hadronic topologies. The next E1 run period (E1E), scheduled to run in early 2002 for 30 effective beam days, will focus on energies from 4-5 GeV. Together these runs will greatly increase our total amount of higher-energy data. Fig. 1 shows an example of the simultaneous coverage of electron kinematics in terms of Q^2 and W for a 4 GeV electron beam incident upon our liquid hydrogen target to highlight the broad kinematic acceptance of the CLAS detector system.

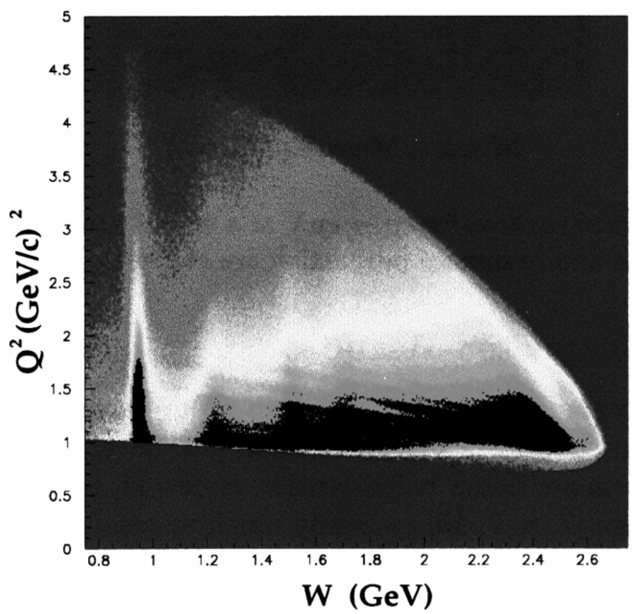


Figure 1: Simultaneous coverage in W and Q^2 for CLAS E1 experiments at 4 GeV beam energy. The elastic scattering peak, as well as the three resonance regions are evident. The low Q^2 cut off is due to the limitation in the forward-angle electron detection for high magnetic field and electrons bending toward the beam axis. This region is covered in lower-field operation or with reversed-field polarity (electrons bending away from the axis).

Most experiments make use of the missing-mass technique to identify one undetected particle in the final state. As an example, Fig. 2 shows the phase space covered in the $ep \to epX$ reaction, where $X = \pi^0$, η, and ω mesons are clearly visible.

The excellent resolution of the time-of-flight system of $\approx$150 psec, allows separation of pions, kaons, and protons over a large momentum range. Fig. 3 shows the mass spectrum of positive hadrons as determined from the hadron time-of-flight and momentum summed over the entire phase space measured in CLAS.

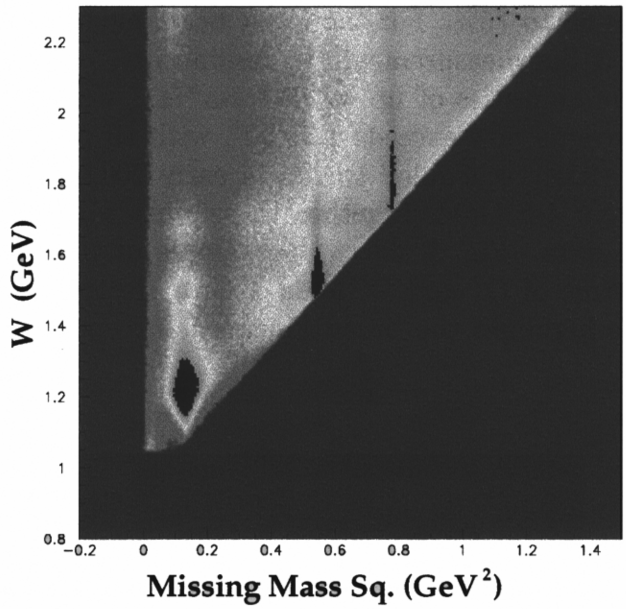


Figure 2: W vs. missing mass squared for $ep \to epX$ at a 4 GeV beam energy. Strong correlations between specific final states and resonance production are evident.

1.3 Results - or Expected Results

At the present time, two analyses from the E1 run group have been published [1, 2], and a third has recently been submitted for publication [3]. Several more analyses have been completed and draft papers are under collaboration review [4, 5, 6], and several more are in an advanced analysis stage [7, 8, 9, 10]. Already our first results, discussed in detail in the contributions to the JLab 2001 Annual Report that accompanies this proposal document, have had significant impact in several areas:

- Our η electroproduction results, together with previous JLab results at higher Q^2, exhibit a consistent picture of the Q^2 dependence of the $S_{11}(1535)$ transition form factor. This allows precise tests of state-of-the-art quark models, which can now be tested against a consistent data set.

- Our results on the $N-\Delta(1232)$ transition basically rule out quark models that do not explicitly include pion cloud contributions. Also, specific chiral soliton models of the nucleon structure do not reproduce our data on the E_{1+}/M_{1+} ratio.

- Our two-pion production data show clear resonance behavior in at least two regions of the invariant hadronic mass spectrum, not seen before in this channel.

- The $n\pi^+$ production channel, for the first time, provides the data needed for a more complete isospin decomposition, and is especially sensitive to the higher-mass I=1/2 states such as the Roper $P_{11}(1440)$ and $D_{13}(1520)$ resonances. The E1 data set vastly dominates the world data on $n\pi^+$ electroproduction in this W and Q^2 regime.

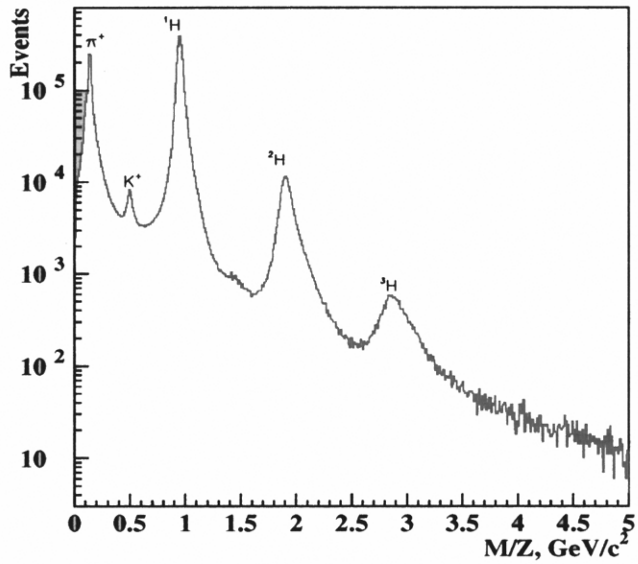


Figure 3: Mass spectrum of positive particles emerging from a carbon target as determined by time-of-flight and momentum. The presence of pions, kaons, protons, deuterons, and tritons is evident.

- Measurement of hyperon production, such as the ground state $\Lambda(1115)$ and the excited state $\Lambda(1520)$, exhibit an intriguingly similar behavior in their Q^2 dependencies, which suggests a common production mechanism. This is in stark contrast to the Q^2 dependence of $K^+\Sigma^0(1193)$ production.

- For the first time, beam asymmetries have been measured in single π^0 and π^+ production. These data will help to determine non-resonant amplitudes in the $\Delta(1232)$ region.

- Single polarization observables have been measured for both $K^+\Lambda$ and $K^+\Sigma^0$ final states. Also, the first ever double polarization observables have been measured for ground-state hyperon production. Both measurements show intriguing energy dependencies with few indications of resonant behavior. Results of these measurements will provide significant tests of models that predict reactions at the amplitude level, and will further our understanding of nucleon structure.

- The exclusive process of "Deep Virtual Compton Scattering" has been unambiguously observed in beam asymmetry measurements for the first time in the E1 run. Not only do these data provide tests of models for the Generalized Parton Distributions, but they also demonstrate the power of a large acceptance detector operating at high luminosity.

In addition to these highlights, preliminary results from the individual E1 experiments have been featured at many conferences and workshops. A list of the speakers and titles are included Appendix B.

1.4 Request for Approval of Time Already Assigned to E1

The run time accumulated for the various energies and targets from the three completed E1 run periods is summarized in Table 1. This table includes the deuteron running time from the E5 run period, since we believe these data can be incorporated into the E1 data base. Also included in this table is the beam time for the E1E run period scheduled for early 2002. We believe that after the completion of the E1E period, the high-energy data set will be large enough that additional high-energy data will not be as useful as data at additional low and intermediate energies. Our proposal for the use of the remaining time originally assigned to the E1 program is indicated in Table 2 in the column labeled as "E1F".

Energy (GeV)	E1A/E1B	E1C	E1D	Sum	% Proposal Luminosity	E1E
	Hydrogen					
1.5/1.6	36	164	-	200	140	-
2.4/2.5	48	178	-	226	85	-
3.0/3.2	-	-	90	90	47	-
> 4.0	60	280	195	535	40	720
	Deuterium					
1.5/1.6	-	-	-	-	0	-
2.4/2.5	-	-	150	150	50	-
> 4.0	-	-	400 (e5)	400	50	-

Table 1: Summary of the total number of beam hours accumulated in the E1 running periods in 1997 (E1A), 1998 (E1B), 1999 (E1C), and 2000 (E1D). Also included is the beam hours scheduled to be collected in the E1E running period in 2002.

The experiments of the E1 run group encompass a large number of individual experiments, each seeking to understand some particular aspect of baryonic structure and dynamics. However, our approach in this first-ever Hall B jeopardy proposal will be to focus on four of our flagship analysis programs to detail why the beam time in the proposed E1F run period is required.

Section 2 of this proposal document focuses on our low Q^2 single pion production experiment. This analysis is timely as there is now a controversy about the very low Q^2 behavior of the E2/M1 ratio for the $N-\Delta(1232)$ transition form factor. Data from the E1 program indicate a smooth trend towards Q^2=0 that disagrees with data from Mainz, Bonn, and LEGS. New data at energies below 1.5 GeV will allow us to resolve the issue by extending the single pion production studies in the $\Delta(1232)$ region to very low Q^2. Section 3 focuses on beam single spin asymmetries in single pion production. This analysis relates to the high quality beam-polarization data, which are very important in separating background and resonance amplitudes in the region of the $\Delta(1232)$ as well as states in the second and third resonance regions. Section 4 focuses on the continuation of the search for so-called "missing resonances" decaying to multi-pion final states. These states have been predicted by quark models to exist but have not been seen in existing experiments with either $N\pi$ or $N\gamma$ reactions. Our final flagship area, related to strangeness physics, is discussed in Section 5. This program will measure cross sections and polarization observables for kaon electroproduction leading to the production of ground state hyperons. These studies with the existing CLAS E1 data have shown very intriguing energy dependencies with few indications of resonant behavior. However, these analyses are plagued by limited statistics. These four aspects of the E1 program will be discussed in detail and serve to justify the program presented in Table 2.

Energy (GeV)	E1A/E1B	E1C	E1D	E1E	E1F	Sum	% proposal luminosity
	Hydrogen						
< 1.5	-	-	-	-	120	120	new
1.5/1.6	36	164	-	-	120	320	220
2.4/2.5	48	178	-	-		226	85
3.0/3.2	-	-	90	-	240	330	170
> 4.0	60	280	195	720	-	1255	92
	Deuterium						
1.5/1.6	-	-	-	-	120	120	80
2.4/2.5	-	-	-	-	-	150	60
3.0/3.2	-	-	-	-	120		new
> 4.0	-	-	-	400(e5)	-	400	40(e5)

Table 2: Summary of the total number of beam hours accumulated in the completed E1 running periods from 1997 to 2000 (E1A → E1D) along with the beam hours planned for 2002 (E1E) and those in this jeopardy proposal (E1F).

The 30 days of beam time that we are seeking for re-approval will be divided into running on both liquid hydrogen and deuterium targets. Our allocation of this beam time is divided into three parts. Ten days is requested at beam energies at and below 1.5 GeV on hydrogen for the low Q^2 single pion production experiments. Ten days are also requested for running at 3.2 GeV on hydrogen for the multi-pion and strangeness physics programs. Finally, proposals PR89-037 and PR89-038 have requested a total of 10 days of beam time for running on a LD_2 target in order to test model predictions of the isospin structure of N^* resonances. Single pion electroproduction proceeds through both isoscalar $A^{(0)}$ and isovector $A^{(3/2)}, A^{(1/2)}$ amplitudes and information about the isoscalar photon excitation can only be achieved by combining measurements from both a proton and neutron target:

$$\begin{aligned} A(\gamma^* p \to n\pi^+) &= \sqrt{2}\,[A^{(0)} + \tfrac{1}{3}A^{(1/2)} - \tfrac{1}{3}A^{(3/2)}] \\ A(\gamma^* n \to p\pi^-) &= \sqrt{2}\,[A^{(0)} - \tfrac{1}{3}A^{(1/2)} + \tfrac{1}{3}A^{(3/2)}] \end{aligned} \quad (1)$$

For the $\Delta(1232)$ resonance, this information can help reduce model dependence in separating the resonant $I = 3/2$ parts of the E_{1+} and S_{1+} quadrupole transitions from the Born dominated backgrounds. For higher-energy excitations, precision measurements of both neutron and proton target multipoles can test single quark transition model (SQTM) predictions of a non-zero spin-orbit term in the transition current of members of the $[\mathbf{70}, \mathbf{1}^-]$

multiplet. For example, $A_p^{(3/2)} = -A_n^{(3/2)}$ for the $D_{13}(1520)$ in the absence of spin-orbit effects. While the data appear to require the spin-orbit term, little information is available on the isoscalar/isovector decomposition and its Q^2 dependence.

We expect CLAS to be ideal for these measurements, since some nuclear structure and acceptance factors cancel by taking ratios of deuteron target π^+/π^- yields and normalizing to proton target yields over a common detector phase space. Up to now we have taken LD_2 data at 2.4 GeV and above 4 GeV (see Table 1) and these data are awaiting processing at JLAB's analysis farm. In order to complement the existing LH_2 data sets at beam energies of 1.5/1.6 GeV and 3.2 GeV, we are requesting 120 hours of LD_2 running at each of those energies, which should complete the proposed program.

2 Single Pion Production at Low Q^2

2.1 Motivation

The CLAS proposal PR89-037, "Electroproduction of the $P_{33}(1232)$ Resonance", encompasses an extensive program to measure the E_{1+}, M_{1+}, and S_{1+} multipole form factors in the $\Delta(1232)$ mass region over a Q^2 range from 0.2 to 4.0 $(\mathrm{GeV/c})^2$. Precise knowledge of N^* transition form factors can constrain hadron models that attempt to describe resonance formation and quark confinement, and possibly can help to identify the appropriate low-energy degrees of freedom. In particular, this proposal was motivated by a need to understand the origin of the non-zero quadrupole strength experimentally observed in the $\gamma^* N \to \Delta \to N\pi$ transition. Simple SU(6) quark models permit only the dominant magnetic dipole (M_{1+}) excitation mode, which occurs via a single quark spin flip. The SU(6) forbidden electric (E_{1+}) and Coulomb (S_{1+}) quadrupole transitions imply non-central, spin-dependent forces [11] within the nucleon, leading to a deformation of the internal current and charge distributions. Such forces are associated with a variety of mechanisms in modern QCD-motivated models: residual tensor interactions between quark pairs (such as gluon [12] and meson exchange [13]) can introduce d-state admixtures, direct photon coupling to a deformed pion cloud [14] or to $q\bar{q}$ exchange currents (leading to the spin flip of two quarks) [15], and collective rotation of a Skyrmion [16].

A crucial experimental test for these hadron models is the magnitude and Q^2 evolution of the multipole ratios $R_{EM} = E_{1+}/M_{1+}$ and $R_{SM} = S_{1+}/M_{1+}$. Unfortunately, the previous measurements from 30 years ago lack sufficient statistical and systematic precision. The new generation of high duty-factor electron accelerators have made possible photo- and electroproduction experiments of unprecedented accuracy. The first round of new measurements of R_{EM} and R_{SM} have been reported in the last five years from facilities at BATES, ELSA, JLAB/Hall C, LEGS, and MAMI. Most recently, analysis of our own measurements using the CLAS detector in Hall B have been completed. All of these new data are summarized in Fig. 4.

The first surprise to emerge from the new results was from the measurements of the cross section and beam polarization asymmetries for the $p(\gamma,\pi^0)p$ and $p(\gamma,\pi^+)n$ photo-pion channels at LEGS [17] and MAMI [18]. Analysis of these data by a number of groups [34] have found $R_{EM} \approx -(2.5 - 3.0)\%$, which is substantially larger than predictions from QCD-inspired constituent quark models (CQM) incorporating one-gluon exchange [12] (color magnetism). This result has shifted the theoretical emphasis to models that explicitly incorporate pion degrees of freedom. For example, chiral soliton models [20], in which quark confinement arises through non-linear interactions with the pion cloud, generally predict larger values for R_{EM} at the photon point. Recent progress in chiral effective field theories [22] and dynamical models [23] that incorporate pion rescattering at the $\gamma N\Delta$ vertex, suggest meson degree of freedoms can strongly enhance the quadrupole strength at low Q^2 and affect the shape of the overall Q^2 dependence.

After an unusually large value for R_{SM} at Q^2=0.127 $(\mathrm{GeV/c})^2$ was reported in a π^0 electroproduction experiment at ELSA in 1997 by Kalleicher [32], a flurry of followup experiments near this Q^2 took place at BATES [31], ELSA [33] and MAMI [30]. Each of these failed to confirm the ELSA measurement. In the meantime, a JLAB/Hall C π^0 electroproduction measurement [19] at Q^2=2.8 and 4.0 (GeV/c)^2, found $R_{EM} < 0$ at the level of a few percent, while R_{SM} was 5-6 times larger and increasingly negative with Q^2. The Hall C results appear to rule out the onset of perturbative QCD, which favors helicity conserving amplitudes for which $R_{EM} \to 1$ and $R_{SM} \to$ constant.

The new CLAS π^0 electroproduction data were obtained at beam energies of 1.645 and 2.445 GeV and covered two overlapping Q^2 intervals spanning the total range $0.4 < Q^2 < 1.8$ (GeV/c)^2. The results, plotted in Fig. 4, were analyzed using about $5-10\%$ of the total events collected so far. The CLAS R_{EM} data clearly exclude the relativistic quark [28, 29] and chiral quark soliton [20] predictions, both of which describe the $Q^2 = 0$ point reasonably well. The chiral models predict a rapidly vanishing R_{EM} for $Q^2 > 0$ (linear sigma model [21], chiral-quark soliton [20]) or diverging behavior (chiral chromodielectric model[21]) inconsistent with the CLAS measurements, although both RQM and chiral models do somewhat better in comparison with R_{SM}.

Another class of models incorporates πN scattering equations [25] and/or a K-matrix unitarization [26] into an isobar model in an attempt to analyze the Q^2 dependence of the $\gamma^* N\Delta$ vertex in the presence of non-resonant backgrounds. These models are typically normalized to photoproduction multipoles and fitted to the well known Q^2 dependence of M_{1+}. A claimed advantage of this approach is that the background effects from pion rescattering can be identified and subtracted from the physical 'dressed' Δ, allowing direct comparison to quark model predictions for the 'bare' Δ, although the uniqueness of this separation has been questioned [24]. Both the dynamical models (DM) of Kamalov and Yang (K-Y) [25] and Sato and Lee (S-L) [23] indicate that meson rescattering accounts for about 40% of the dressed M_{1+} form factor at $Q^2 = 0$, and nearly 100% of the quadrupole form factors at low Q^2.

The other curves in Fig. 4 show predictions from the DM and MAID models [27] for the Q^2 dependence of R_{EM} and R_{SM}. More accurately, these models estimate deviations from scaling behavior due to pion rescattering effects. Both DM models and MAID were fitted to the Hall C cross section data and the extracted multipole ratios show considerable model dependence. At high Q^2, the differences between the model curves mostly reflect off-shell pion rescattering effects that are included in the DM, but absent in MAID. As $Q^2 \to 0$, the MAID and K-Y DM R_{SM} curves are strongly influenced by the BATES and Mainz R_{SM} measurements, which are significantly lower than the ELSA/ELAN points. The S-L DM curve, which was not fitted to those data, shows a trend more consistent with the CLAS and ELSA/ELAN measurements, although the CLAS data lie closer in magnitude to the K-Y DM overall. For the low Q^2 R_{EM} points, the BATES measurement has a large error due to model dependence, while the ELSA/ELAN R_{EM} points lie closer to the MAID curve. The CLAS data are mostly consistent with the K-Y DM curve.

To summarize, we feel that the JLAB measurements of the $N - \Delta$ quadrupole transition form factors show a Q^2 dependence and magnitude that can best be described by nucleon models which incorporate pion degrees of freedom. To further constrain those models, more accurate data are required both at high Q^2, to address the off-shell pion rescattering terms in the dynamical models, and at low Q^2, where the size of the pion cloud relative to the valence quark core can strongly influence the Q^2 dependence. In particular, the CLAS measurements should be extended to overlap the Q^2 region of the new BATES, ELSA, and MAMI measurements, in order to provide an independent check of the interesting R_{SM} results near Q^2=0.127 (GeV/c)^2. The importance of measuring both R_{EM} and R_{SM} is important in this regard, as the model dependence clearly affects the Q^2 dependence of these ratios differently.

2.2 Proposed Measurement

We are proposing to extend the current Q^2 coverage of the CLAS single pion electroproduction program down to $Q^2 = 0.05$ (GeV/c)^2 in order to overlap the region covered by the BATES, ELSA, and MAMI measurements. We plan to obtain sufficient statistics to produce at least five Q^2 bins in the interval $0.05 < Q^2 < 0.3$ (GeV/c)^2, although our coverage with CLAS will be continuous, in contrast to the previous fixed-angle measurements. Both π^+n and π^0p final states will be measured using LH_2 and LD_2 targets enabling a complete isospin amplitude analysis. Polarized beam will provide access to the fifth structure function, which will provide information about non-resonant backgrounds. To reach this low Q^2 region with CLAS will require running at beam energies of 0.8 and 1.2 GeV.

2.3 Feasibility of Experiment

Fig. 5 shows the predicted change in the shape of the π^0p C.M. angular distributions that result from setting E_{1+} and S_{1+} to zero in the MAID2000 unitary isobar model. This model describes the existing data reasonably well and should give a realistic estimate of our experimental sensitivity in the low Q^2 region. From the plots it is seen that maximum sensitivity near the $\Delta(1232)$ resonance peak occurs at $\cos\theta^*_\pi = -1, 0, 1$ for E_{1+} and at $\cos\theta^*_\pi$ = -0.5,0.5 for S_{1+}. Furthermore, the overall sensitivity is maximized in the (e, e') scattering plane ($\phi^*_\pi = 0^0, 180^0$). Nevertheless, complete C.M. coverage is desirable in order to reduce the influence of systematic uncertainties in the overall normalization and to better measure the shape of the angular distributions.

Unfortunately there are fundamental limitations to achieving full kinematic coverage at low Q^2 that apply to any detector configuration. Below we discuss several inter-related issues associated with running CLAS at low Q^2:

1. Center of mass (C.M.) coverage
2. CLAS torus polarity
3. Proton energy loss

We begin with a discussion of the C.M. coverage available using CLAS at the Q^2 settings proposed for this measurement.

2.3.1 π^0p C.M. Coverage

The 3-momentum transfer $\vec{q}$ of the virtual photon defines the z-axis of the $\gamma^*p \to \pi^0p$ C.M. frame. In the lab frame, the proton emission angle θ_q (with respect to $\vec{q}$) is given in terms of the C.M. angle θ^* by:

$$\tan\theta_q = \frac{\sin\theta^*}{\gamma_o(\cos\theta^* + \beta_o/\beta^*)}, \tag{2}$$

where $\beta_o = |\vec{q}|/(\nu + M_p)$, $\gamma_o = (1 - \beta_o^2)^{-1/2}$ and $\beta^* = p^*/E^*$. The magnitude of the proton C.M. momentum is:

$$p^* = \frac{\left(W^2 - (M_p - m_{\pi^o})^2\right)^{1/2}\left(W^2 - (M_p + m_{\pi^o})^2\right)^{1/2}}{2W}. \tag{3}$$

The maximum angle θ_q^{max} occurs when $\cos\theta^* = -\beta^*/\beta_o$, and is a strong function of Q^2 and W. This is illustrated in Fig. 6, which shows the mapping of the $\pi^0 p$ C.M. angles θ^* and ϕ^* onto the proton lab scattering angles θ_p and ϕ_p at the peak of the $\Delta(1232)$ resonance, for the case in which the scattered electron is detected at $\phi_e = 0°$. For $Q^2 > 0.4$ (GeV/c)^2, nearly 100% of the $\pi^0 p$ C.M. can be measured using a single sector of CLAS, while for $Q^2 < 0.4$ (GeV/c)^2, an increasing amount of C.M. coverage is lost to the torus coils and the beam pipe as θ_q^{max} increases.

The Lorentz boost defined by eq.(2) also relates θ^* to the proton laboratory angle θ_p and momentum p. For a fixed Q^2, W, and beam energy, these variables are completely correlated as shown in Fig. 7. For each Q^2 setting in the range $Q^2 = 0.05 - 0.4$ (GeV/c)^2, the figure shows equally spaced θ^* points (separated by 5°) mapped to the corresponding (θ_p, p) points for the proton. Also shown are curves indicating the limits of the CLAS momentum and angular acceptance for protons (both for inbending and outbending). Note that for Q^2 <0.2 (GeV/c)^2, coverage at forward π^0 C.M. angles begins to disappear due to proton energy loss in the target, and by Q^2=0.05(GeV/c)^2, only $\theta^* > 45°$ can be measured.

Despite the less than 100% C.M. acceptance at low Q^2, CLAS still offers a substantial increase in C.M. coverage compared to the ELSA/ELAN, BATES/OHIPS and MAMI measurements. As evident in Figs. 6 and 7, this is largely due to the six-fold symmetry of CLAS, which allows sectors adjacent and opposite to the direction of the $\vec{q}$ vector to pick up some of the coverage that would be lost in previous configurations.

2.3.2 CLAS Torus Polarity

The nominal magnetic field polarity used when running CLAS with electron triggers bends negative particles inward (toward the beam). This provides the most uniform response in the Cerenkov detectors, whose mirror optics are optimized for inbending electrons. Also because of the θ_e dependence of $\int \vec{B} \cdot d\vec{l}$ in CLAS, running at normal polarity provides a low Q^2 cutoff which is nearly independent of W. Table 3 shows the minimum Q^2 values achievable at various beam energies and torus currents. To achieve a Q^2 as low as 0.05 (GeV/c)^2 will require a beam energy of 800 MeV.

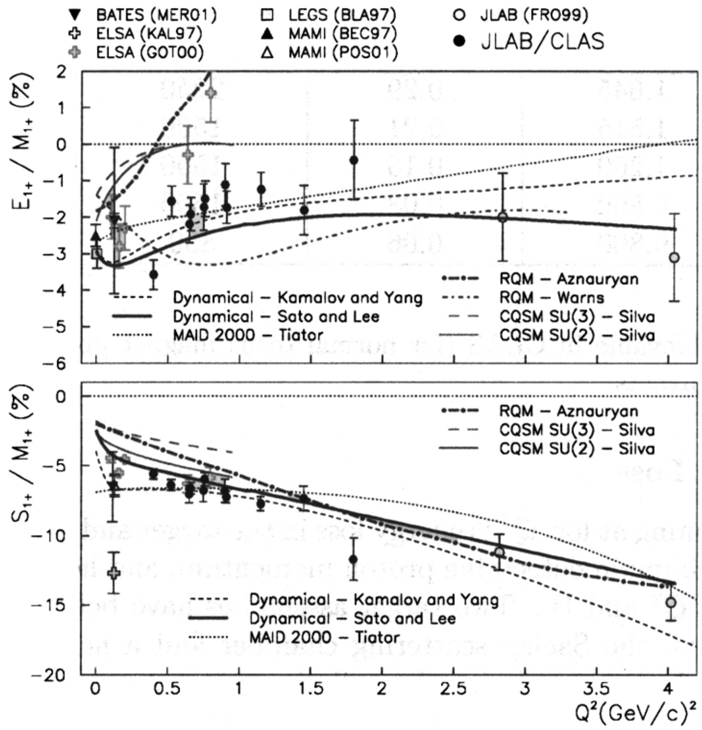
An alternative to running at lower beam energies to achieve low Q^2 would be to reverse the torus polarity and run with outbending electrons. This is typically done during inclusive experiments with the CLAS polarized target, where Q^2 as low as 0.05 (GeV/c)^2 can be achieved at beam energies up to 2.5 GeV. Unfortunately, since reversed torus polarity bends positive hadrons inward, the result is an unacceptable loss of C.M. coverage for exclusive reactions, as shown in Fig. 7 for the $\pi^0 p$ channel.

Beam Energy (GeV)	Minimum Q^2 (GeV/c)^2	Torus Current (Amps)
1.645	0.29	2250
1.515	0.21	1500
1.200	0.15	1500
0.800	0.08	1500
0.800	0.06	800

Table 3: Minimum Q^2 achievable in CLAS (for normal torus magnet polarity) at the indicated beam energies and torus currents.

2.3.3 Proton Energy Loss

Another constraint to running at low Q^2 is energy loss in the target and surrounding materials. This determines the minimum detectable proton momentum, and hence the forward-most C.M. angle θ^*_π at a given Q^2 and W. Two target assemblies have been used in CLAS electroproduction experiments, the Saclay scattering chamber and a newer polystyrene foam composite chamber. The latter was designed to eliminate structural Mylar window frames found in the Saclay chamber close to the target cell, from which protons could multiple scatter into the CLAS acceptance. Preliminary GEANT simulations using both scattering chambers suggest, however, that the foam chamber with its thicker walls may cause unacceptable energy losses and multiple scattering for low-energy protons, compared to the Saclay chamber. Note that the proton threshold indicated in Fig. 7 is based on the Saclay chamber. These studies are continuing to evaluate the relative merits of both chambers and the overall impact on the physics analysis.



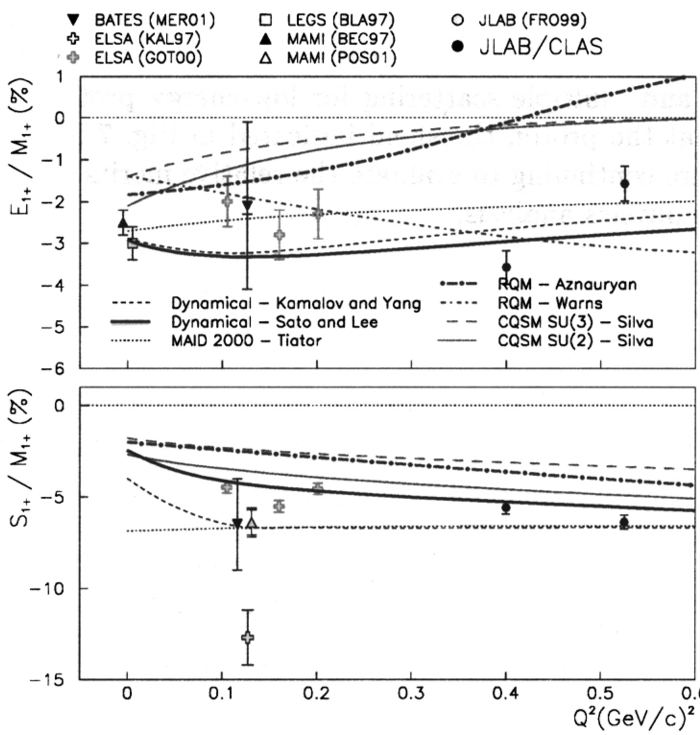


Figure 4: Recent measurements of Q^2 dependence of quadrupole ratios $R_{EM} = E_{1+}/M_{1+}$ and $R_{SM} = S_{1+}/M_{1+}$ from photo- and electroproduction of $\Delta(1232) \to p\pi^0$ channel. Each plot shows a different Q^2 range for clarity. Curves show recent model calculations: chiral quark-soliton[20], dynamical pion cloud[23, 25], MAID2000[26], relativistic quark[28, 29]. CLAS measurements ($\bullet$) have statistical errors only. Other R_{EM} points are from BATES[31], ELSA/ELAN[33], LEGS[17], JLAB/Hall C[19], and MAMI[18]. Other R_{SM} points are BATES[31], ELSA[32], ELSA/ELAN[33], JLAB/Hall C[19], and MAMI[30]. Note the larger error on the BATES points are estimates of model dependence.

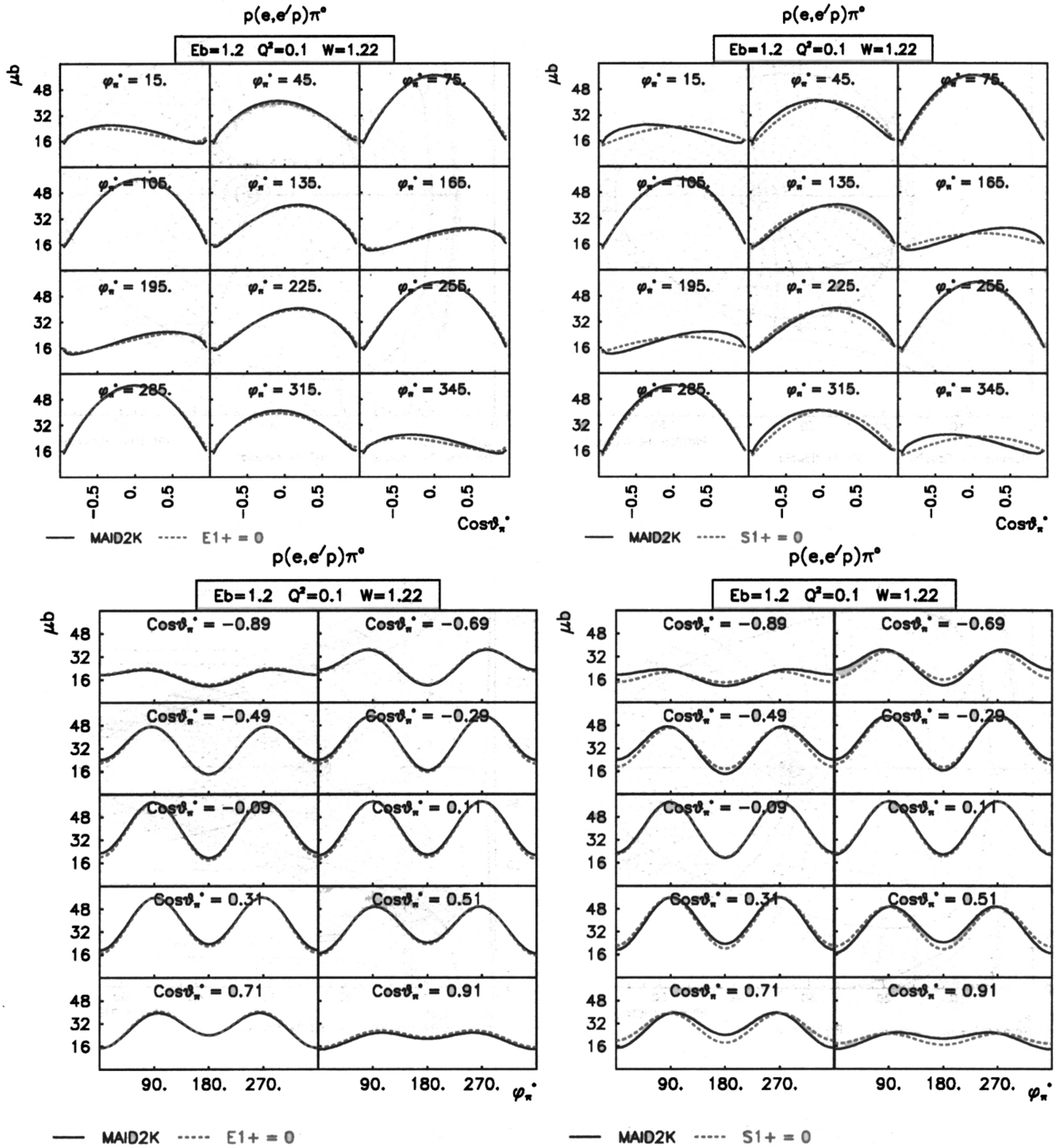


Figure 5: Predicted sensitivity of C.M. angular distributions to E_{1+} and S_{1+} multipoles in the $\Delta(1232) \to p\pi^0$ channel using the MAID2000 unitary isobar model. The solid curve shows the nominal MAID2000 prediction, while the dashed curves show the result from setting $E_{1+} = 0$ (left) and $S_{1+} = 0$ (right).

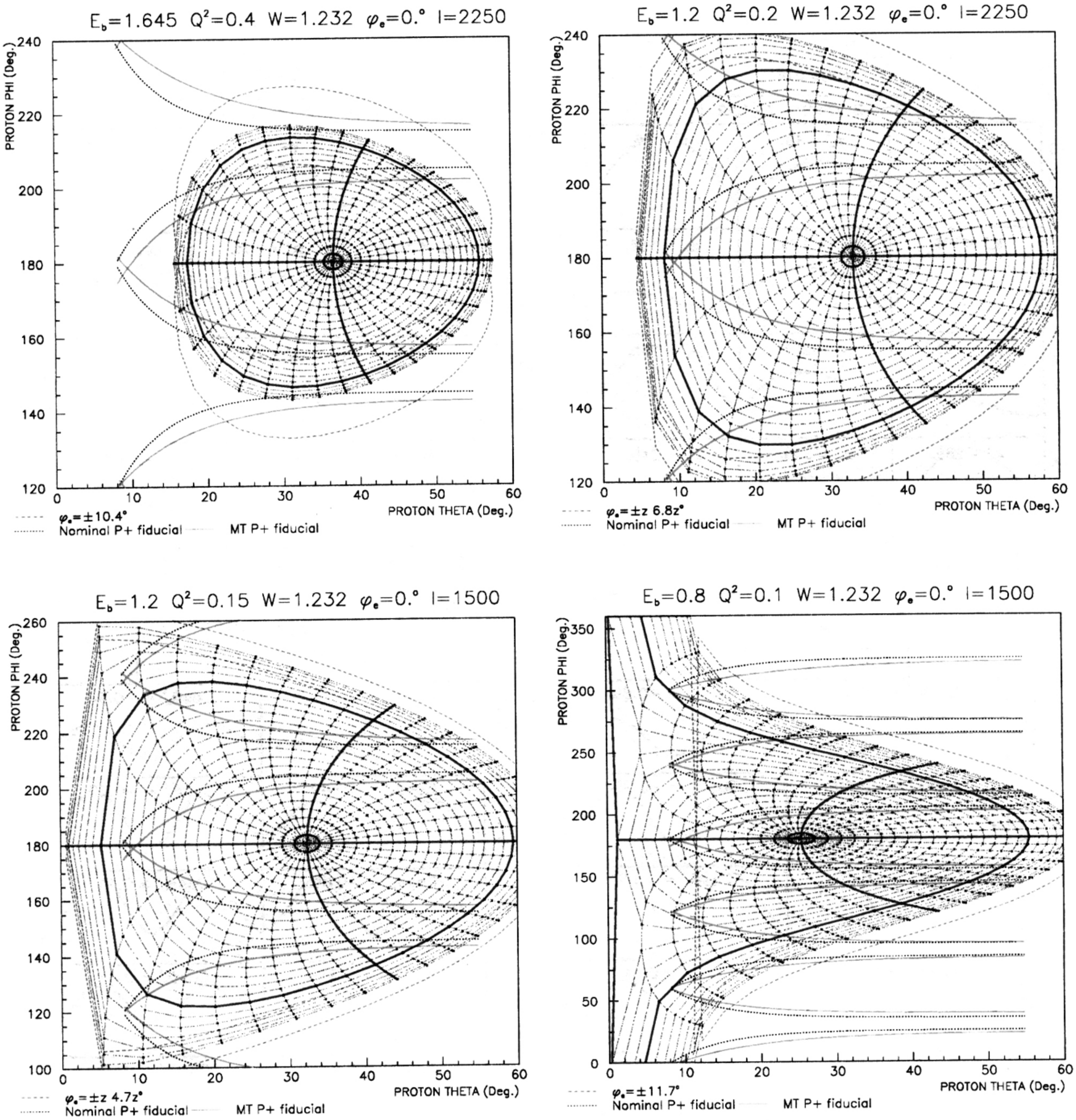


Figure 6: Mapping of $\pi^0 p$ C.M. angles θ^* (concentric circles) and ϕ^* (radial lines) onto the laboratory angles of the proton (θ, ϕ) for various kinematic settings discussed in text. Grid points are at 5° intervals of θ^* and 10° of ϕ^*. Bold grid lines indicate (starting clockwise from left) $\phi^* = 0°, 90°, 180°, 270°$, and $\theta^* = 90°$. Only $\cos\theta^* \geq -\beta^*/\beta_0$ is shown (see text). Grid calculated for electron detected at midplane of Sector 1 ($\phi_e = 0°$), while dashed lines show additional C.M. coverage permitted by CLAS electron fiducial ϕ_e acceptance. Dotted and solid lines show CLAS nominal and mini-torus limited proton fiducial acceptance.

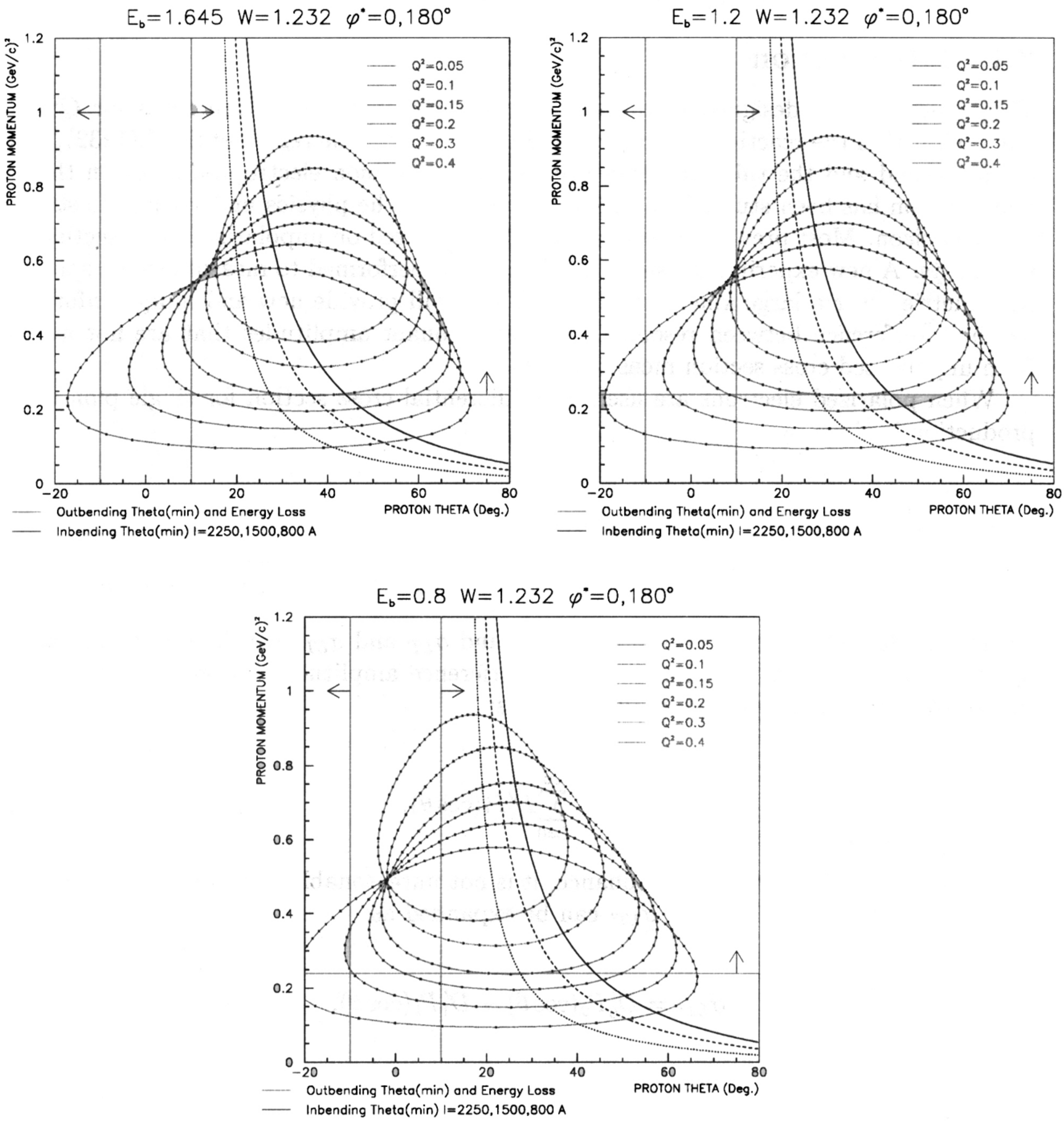


Figure 7: Mapping of $\pi^0 p$ C.M. angle θ^* into the proton laboratory scattering angle θ and momentum p at $E_B = 1.645, 1.2, 0.8$ GeV and $W = 1.232$ GeV for the Q^2 points indicated. Grid points are at 5° intervals in θ^*. The (minimum,maximum) proton lab momentum corresponds to $\theta^*_\pi = (0°, 180°)$, at which point $\theta = \theta_{\gamma^*}$, the direction of the 3-momentum transfer $\vec{q}$. Points to the (right,left) of $\vec{q}$ correspond to $\phi^*_\pi = (0°, 180°)$. Other curves show the limits of the CLAS proton acceptance due to outbending angular acceptance (vertical lines), inbending angular acceptance (curved lines), and target energy loss (horizontal line). Note that negative proton θ corresponds to detection of the proton in the sector of CLAS 180° away from $\vec{q}$.

3 Pion Single Spin Beam Asymmetries

3.1 Introduction

This experiment is designed to measure the single spin beam asymmetries for Q^2=0.3 - 0.9 (GeV/c)^2 in the reactions $p(\vec{e}, e'p)\pi^0$ and $p(\vec{e}, e'\pi^+)n$ in the region of the $\Delta(1232)$, as well as the second and the third resonance regions . Single pion electroproduction in the resonance region has been studied as a means of exploring the physics underlying the structure of the nucleon. Most previous measurements have focused on unpolarized cross section measurements. A new experiment using CLAS has been performed to measure single spin beam asymmetries over a large kinematic range. These will provide new and unique information on the interference between resonant and non-resonant amplitudes that are not available from unpolarized cross section measurements.

When polarized electrons are used, the differential cross section for single pion electroproduction is given by:

$$\begin{aligned} \frac{d\sigma}{d\Omega} = \sigma_T + \epsilon\sigma_L &+ \epsilon\sigma_{TT}\sin^2\theta\cos 2\phi \\ &+ \sqrt{2\epsilon(\epsilon+1)}\sigma_{LT}\sin\theta\cos\phi + h\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}\sin\theta\sin\phi, \end{aligned} \tag{4}$$

where h is the helicity of polarized electrons, and σ_{LT} and $\sigma_{LT'}$ are the real and imaginary parts of the same transverse-longitudinal interference amplitudes. In general, $\sigma_{LT'}$ can be expanded in terms of Legendre polynomials as:

$$\sigma_{LT'} = \sum_{l=0}^{\infty} D'_l P_l(\cos\theta). \tag{5}$$

For the case of the $\Delta(1232)$ resonance, it is not unreasonable to restrict oneself to S and P-wave amplitudes. In this case $\sigma_{LT'}$ can be expanded as:

$$\sigma_{LT'} = D'_0 P_0(\cos\theta) + D'_1 P_1(\cos\theta), \tag{6}$$

where,

$$\begin{aligned} D'_0 &= -Im(S^*_{0+}(M_{1-} - M_{1+} + 3E_{1+}) + E^*_{0+}(S_{1-} - 2S_{1+})) \\ D'_1 &= -6Im(S^*_{1+}(M_{1-} - M_{1+} + 3E_{1+}) + E^*_{1+}(S_{1-} - 2S_{1+})). \end{aligned} \tag{7}$$

If there were no background amplitudes, D'_0 and D'_1 would be identically zero. Thus any non-zero D'_0 and D'_1 contributions would have to come from interferences from resonant amplitudes with non-resonant ones.

The second resonance region is dominated by the excitation of two resonances, the $S_{11}(1535)$ and the $D_{13}(1520)$, and the third resonance region is dominated by the $F_{15}(1700)$. Several other states in these resonance regions also contribute, but so weakly that it has been difficult to extract much detail about their electromagnetic structure. Our measurements will greatly improve the accuracy of the electromagnetic amplitudes for the dominant resonances and other weaker ones, which are complementary to unpolarized cross section measurements. It is also hoped that the nature of the $P_{11}(1440)$ Roper resonance can be clarified. This resonance has been observed in photoproduction, but only very weakly in electroproduction. This new observable will provide valuable constraints for different models.

3.2 Data Analysis and Results

The data were taken using a polarized electron beam of 1.515 GeV at 100% duty factor incident on a liquid hydrogen target. Scattered electrons and protons were detected in CLAS. The electron beam polarization was approximately 70%. For this analysis, we performed an energy-independent multipole analysis. The electron helicity-dependent response function, $\sigma_{LT'}$ is isolated by measuring the single spin beam asymmetry, $A_{LT'}$ which is defined as:

$$A_{LT'} = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-). \tag{8}$$

For an absolute normalization, we used the measured unpolarized cross sections. In the $\Delta(1232)$ resonance region, D'_0 and D'_1 in eq.(7) were extracted by fits to the polar angle distributions of $\sigma_{LT'}$ up to the D-wave contributions. Fig. 8 shows the results for $\sigma_{LT'}$ compared with MAID98 [27] and Sato-Lee [35] calculations. Fig. 9 shows our results for D'_0 and D'_1, which are also compared with MAID98, MAID2000, and Sato-Lee calculations. The error bars on these very preliminary data include statistical uncertainties only. A strong non-zero $\sigma_{LT'}$ over the entire $\Delta(1232)$ resonance region indicates significant contributions from non-resonant amplitudes. Both the MAID and Sato-Lee calculations qualitatively describe our results, but the accuracy of our measurements is good enough to differentiate between models.

For higher resonances, $\sigma_{LT'}$ is also extracted in $p(\vec{e}, e'\pi^0)p$ and $p(\vec{e}, e'\pi^+)n$ as shown in Fig. 10 and Fig. 11. Comparison of our data with MAID2001 calculations shows substantial differences. It is quite clear that our measurements will provide new and valuable information about the electroproduction amplitudes in detail in these resonance regions.

3.3 Beam Time Request

Data from 1.5 GeV beam energy runs provide good angular and momentum resolution, good coverage in W up to 1.7 GeV for the resonance region, and a reasonable Q^2 range from 0.3 to 0.9 $(\text{GeV/c})^2$. Currently we have limited statistics at this energy to allow for enough bins in W, $\cos\theta$, and ϕ. All of which are essential for our multipole analysis. We request an additional 120 hours of running at 1.5 GeV, 40% torus field in order to improve our statistics by a factor of two. The additional data sample is critical for the higher Q^2 bins that will enable us to study the Q^2 dependence. We feel that this additional beam time is very important to these new measurements.

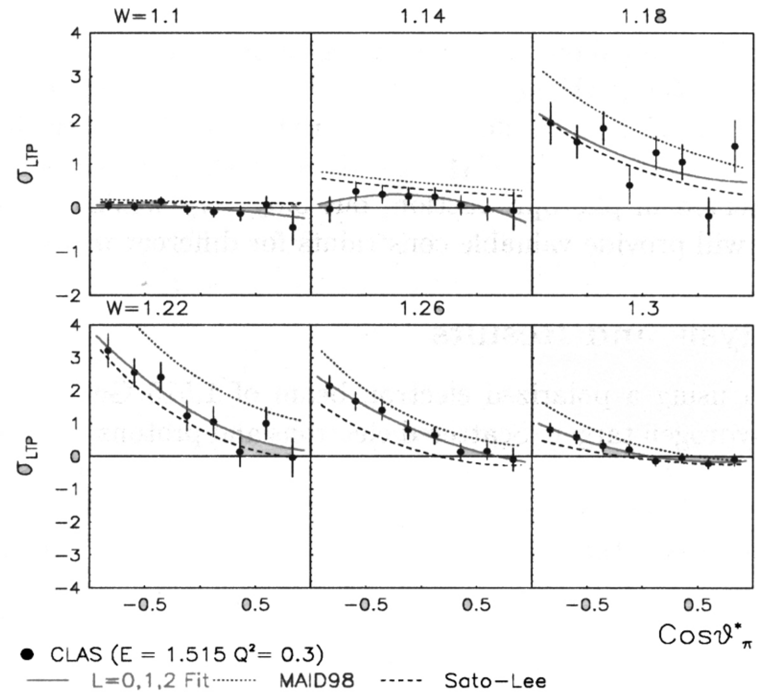


Figure 8: Preliminary CLAS data for $\sigma_{LT'}$ for different W (GeV) bins in $p(\vec{e}, e'\pi^0)p$ as a function of $\cos\theta$ at Q^2= 0.4 (GeV/c)^2. Error bars are statistical only.

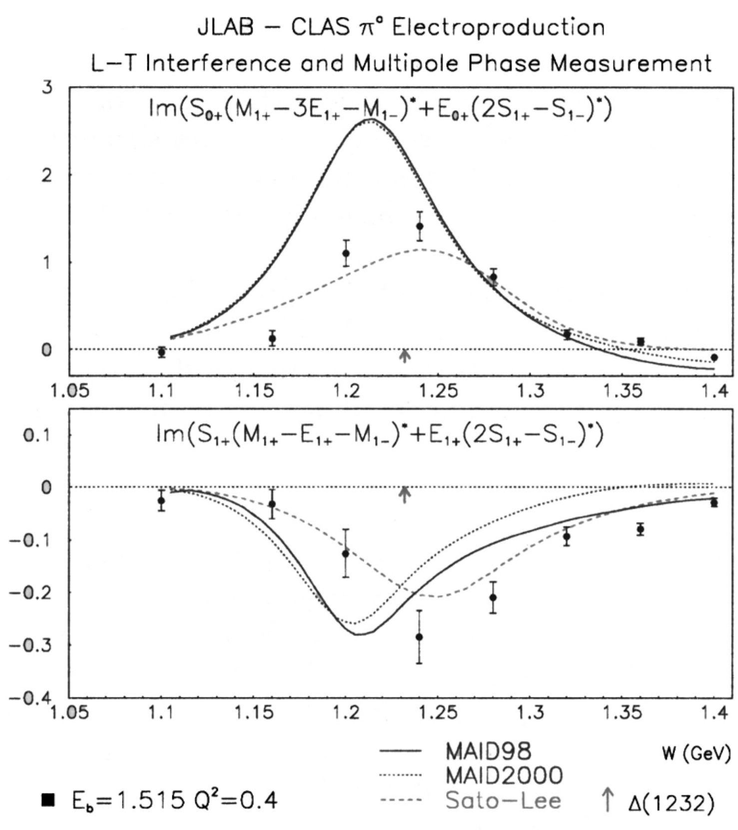


Figure 9: Preliminary CLAS data at Q^2= 0.4 (GeV/c)^2 for D'_0 (top) and D'_1 (bottom) (μb) in $p(\vec{e}, e'\pi^0)p$ as a function of W (GeV). Error bars are statistical only.

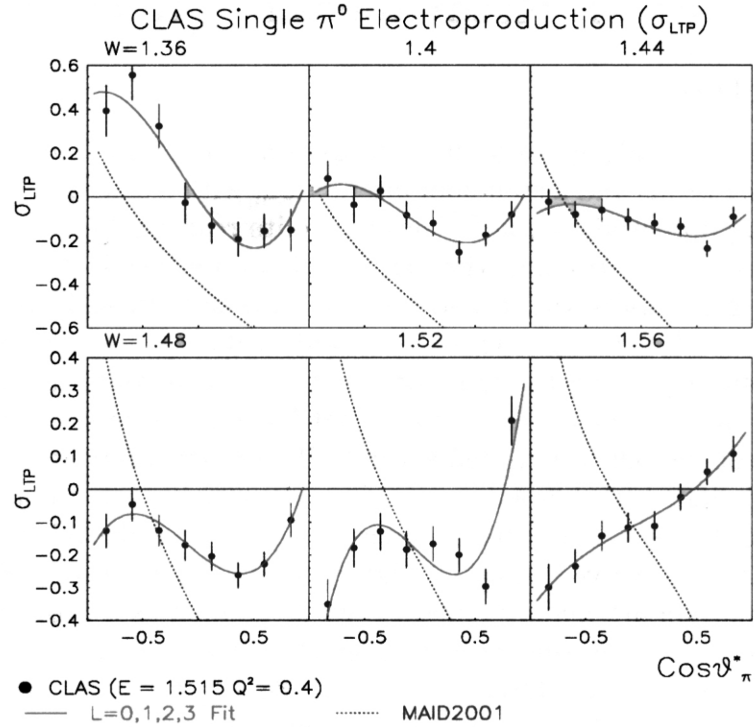


Figure 10: Preliminary CLAS data for $\sigma_{LT'}$ for different W (GeV) bins in $p(\vec{e}, e'\pi^0)p$ as a function of $\cos\theta$ at Q^2= 0.4 (GeV/c)^2. Error bars are statistical only.

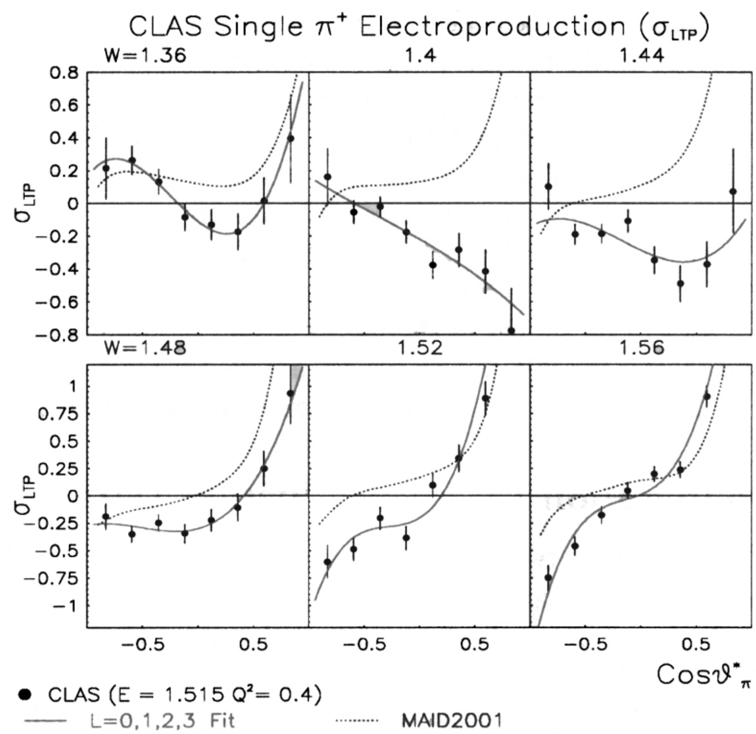


Figure 11: Preliminary CLAS data for $\sigma_{LT'}$ for different W (GeV) bins in $p(\vec{e}, e'\pi^+)n$ as a function of $\cos\theta$ at Q^2= 0.4 (GeV/c)^2. Error bars are statistical only.

4 Missing Baryon Resonances in Multi-Pion Channels

4.1 Introduction

Any quark model incorporating the basic features of approximate SU(6) symmetry with explicit flavor-breaking terms and a spin-spin interaction, with a spatial wavefunction obtained from some confining potential, is able to account quite reasonably for many observed properties of baryon states. In particular, the main static properties of the ground state and the first excited states are usually well accounted for. However, in addition to the well-known discrepancies between electromagnetic properties like calculated and measured form factors, there is a major issue regarding the number of states: the symmetric quark model predicts a number of states in the second orbital band that have not been seen in experiments. This "missing states" problem has stimulated several different explanations.

In quark models [36] with hyperfine mixing and explicit meson couplings, it turns out that some states could have a very weak single pion coupling, decaying predominantly into multi-pion channels, as observed in many high-lying measured states. Since the sources of experimental information are mainly reactions with the pion as a projectile or a single pion photoproduced from a nucleon, the absence of baryon states with very small pion coupling in those data sets is not surprising. Other models [37, 38, 39] based on various meson creation assumptions have found similar results. An alternative explanation, such as given by the Quark Cluster Model [40], is that a reduction in the spatial degrees of freedom can reduce the number of excited states.

From this introduction, it is clear that multi-pion production in both photoproduction and electroproduction can test these different models. In particular, the two pion and omega exclusive channels provide access to states that are weakly coupled to the pion and eta mesons, and are therefore barely measurable in single pion and eta electroproduction. Needless to say, the high luminosity, acceptance and good momentum resolution of the CLAS detector, make it an ideal tool for performing such studies. In fact, several experiments to search for missing baryon states are currently in progress at JLab. However, because of the particular settings of beam energy and magnetic field, data on these reactions have been collected only in the range $0.2 < Q^2 < 1$ $(\mathrm{GeV/c})^2$ for W up to about 1.9 GeV, and for $Q^2 > 1$ $(\mathrm{GeV/c})^2$ for W above 2 GeV. As will be shown in the next section, it would be useful to complement these data with data in the low Q^2 region for W above 1.9 GeV. Additionally, these data may provide evidence at low momentum transfer for high-mass missing states.

4.2 CLAS Double Pion Electroproduction Data

Approximately 10^9 events from two separate run series performed in the spring 1999 E1C CLAS run period are being used to study two pion electroproduction as part of experiments E91-024 and E93-006. As an example of the detailed results that have been obtained, the total cross sections for reaction $ep \to e'p\pi^+\pi^-$ at three different Q^2 intervals are shown in Fig. 12 for W in the resonance region. Since this figure shows unpublished results from a full data set, arbitrary units are shown. However, the absolute value has been established. It is clear from the picture that the region corresponding to high W and low Q^2 is not covered due to the kinematic limitations previously mentioned.

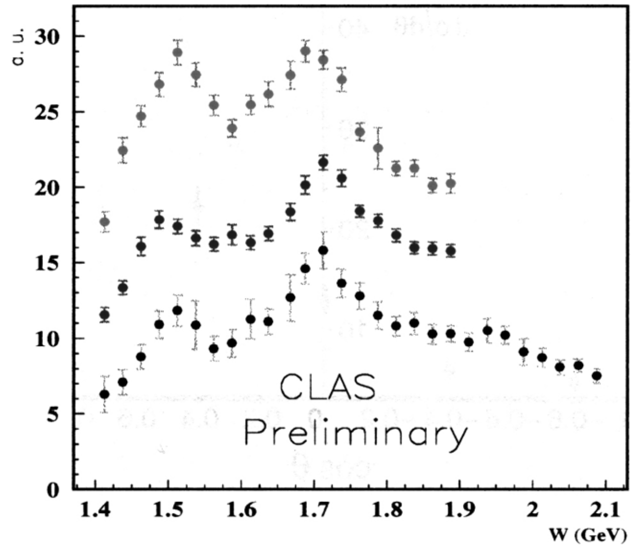


Figure 12: Total virtual photon cross section as a function of W for $ep \to ep\pi^+\pi^-$ from CLAS at Q^2 between 0.5 and 0.8 $(\mathrm{GeV/c})^2$ (E_{beam}=2.567 GeV, red points), between 0.8 and 1.1 $(\mathrm{GeV/c})^2$ (E_{beam}=2.567 GeV, blue points), between 1.1 and 1.5 $(\mathrm{GeV/c})^2$ (E_{beam}=4.247 GeV, black points). Error bars are statistical only.

4.3 CLAS Omega Electroproduction Data

Approximately 10^9 events from five separate run series comprising the spring 1998 E1B and spring 1999 E1C CLAS run periods are being analyzed to study ω meson electroproduction. The angular distributions measured for the reaction $ep \to e'p\omega$ are characterized by a monotonic fall off with increasing production angle for $W > 2.0$ GeV as shown in Fig. 13. This behavior is characteristic of diffractive and/or t-channel π exchange processes. However, as shown in Fig. 14, in the W region from threshold to about 2.0 GeV, the cross section is enhanced in the backward direction, providing an indication for a strong contribution from the nucleon pole (u-channel) or s-channel resonances. Investigations of the ϕ^* azimuthal angle dependence and the angular momenta are in progress. Again, the region corresponding to high W and low Q^2 is not covered due to the kinematic limit previously mentioned.

4.4 Beam Time Request

Based on our experience running with the retracted polarized target during the EG1 running period, as well as extrapolating from existing E1 measurements, we have determined that using a beam energy of 3.2 GeV at 60% torus field with the target retracted by 50 cm from the nominal position, we will be able to achieve Q^2 coverage down to less than 0.5 $(\mathrm{GeV/c})^2$, with W extending up to about 2.2 GeV. This will allow us to cover a region where the resonant content is very poorly known, both for two pion and omega electroproduction. Given a typical luminosity of a few 10^{33} $\mathrm{cm^{-2}s^{-1}}$ and considering the reduction in cross section that occurs with increasing beam energy, we found that with 240 hours of 100% efficient running, we may achieve the same statistics as shown in Fig. 12, thereby completing a crucial portion of the kinematics involved in higher-mass and missing resonance studies.

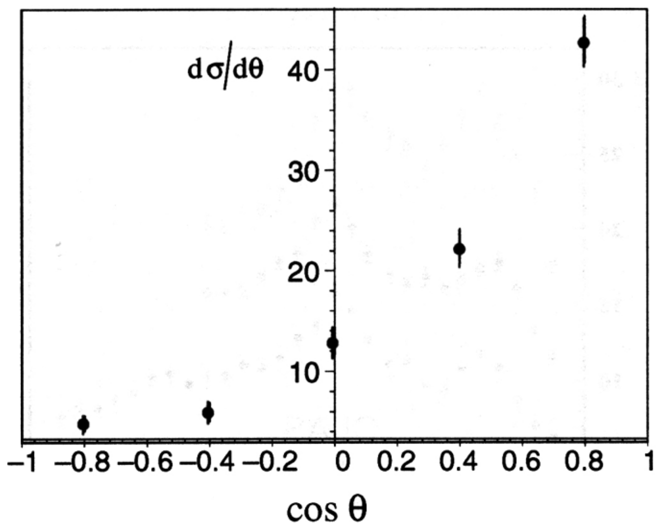


Figure 13: Preliminary results from CLAS for omega electroproduction at E_{beam}=4.2 GeV showing the differential cross section (arbitrary units) at W=2.15 GeV.

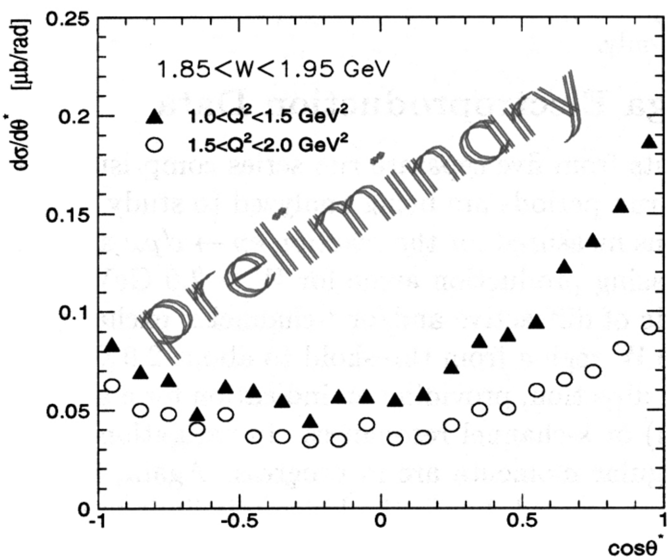


Figure 14: Preliminary results from CLAS for ω electroproduction at E_{beam}=4.2 GeV showing the differential cross section for a selected W range for two Q^2 intervals.

5 Exclusive Kaon Electroproduction

5.1 Introduction

The strangeness physics program in Hall B encompasses a number of different analyses, including both cross section and polarization measurements on ground state and excited state hyperons at beam energies from 2.4 to 4.8 GeV. The experiments involved in this program are E89-043, E93-030, E95-003, E99-006, and CAA-2000-1. The overall goal of this program is to improve our understanding of the open strangeness production reaction mechanism over the entire resonance region. During the last decade, there has been considerable effort to better understand the associated baryonic and mesonic degrees of freedom of this process in an effort to improve the theoretical models for kaon electroproduction.

Our present state of understanding is still limited by a sparsity of data. Model fits to the existing cross section data are generally obtained at the expense of many free parameters, which leads to difficulties in constraining existing theoretical descriptions. Moreover, cross section data alone are not sufficiently sensitive to fully understand the reaction mechanism, as they probe only a fraction of the response. In this regard, measurements of spin observables are essential for continued theoretical development in this field, and as such, are an integral part of the CLAS strangeness program.

5.2 Results and Discussion

Our first results from the CLAS data acquired in 1998 and 1999 are nearly ready for publication. This initial work will provide differential cross section measurements and angular distributions for ground state Λ and Σ^0 production, as well as for $\Lambda(1520)$ production [9, 3]. In conjunction with these analyses, the large angular coverage of CLAS has allowed for the separation of the ground-state hyperon interference structure functions σ_{TT} and σ_{TL} over a broad kinematic range (see Fig. 15). Our data show significant differences in the dynamics underlying Λ and Σ^0 production. Each of these efforts will no doubt improve existing low-energy theoretical descriptions of the strangeness production process. Additionally they will be used to probe the excitation and decay of predicted N^* resonances [41] as a function of W, Q^2, and t, which will serve to test the validity of non-perturbative QCD over the kinematics of the resonance region.

Over these same kinematics, we have also measured the induced hyperon polarization, as well as the first-ever beam-recoil double polarization observables. Because hyperon-production models have been tuned to match the existing cross-section data, available mostly at small t, comparison of their predictions of polarization observables with data are expected to provide for deeper insight into the dynamics underlying both the resonant and non-resonant strength.

Given the present successes of our strangeness physics program, it is important that we also understand that there are several key areas that are still plagued by limited data samples. This will ultimately serve to limit our theoretical understanding. In these areas the additional data that could be acquired with the remaining E1 beam time could make a substantive impact on the quality of the program rather than simply a reduction in statistical error bars. One analysis in need of higher statistics is the hyperon polarization program. To

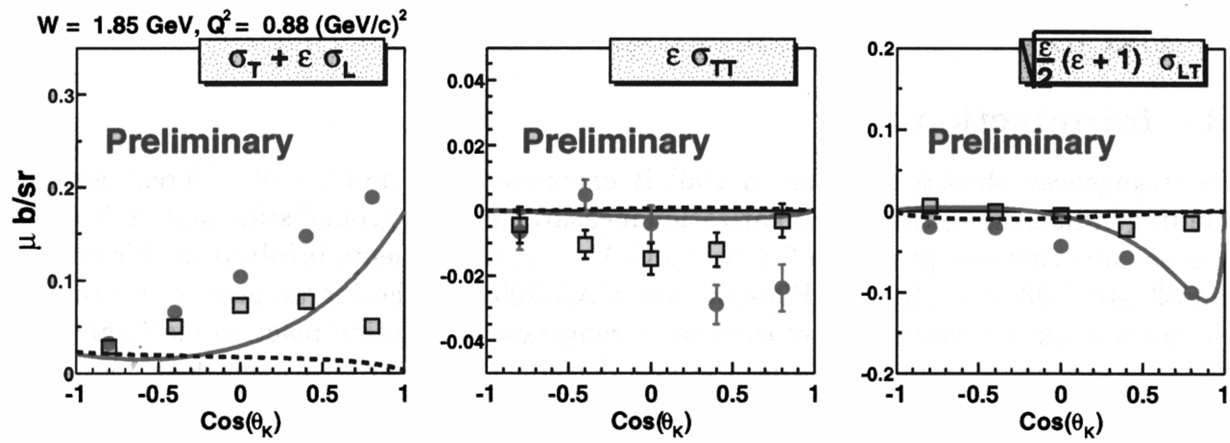


Figure 15: Structure functions $\sigma_T + \epsilon\sigma_L$, σ_{TT}, and σ_{TL} for $K\Lambda$ (circles) and $K\Sigma^0$ (squares) electroproduction as a function of $\cos\theta_K^*$ from preliminary CLAS analysis at 2.567 GeV, W=1.85 GeV, and Q^2=0.88 (GeV/c)^2. The curves (Λ:solid,Σ:dashed) correspond a hadrodynamic calculation [42].

date we have acquired data sets with polarized beam at energies of 2.5, 3.1, and 4.2 GeV. Each set amounts to roughly 1 billion inclusive electron triggers. However, in measuring the outgoing hyperon polarization, we must detect three particles in the final state, namely the scattered electron, the electro-produced kaon, and the proton from the mesonic decay of the Λ hyperon. This final state has an average geometric acceptance of 5% in CLAS. Table 4 provides an overview of the total number of ground-state hyperons whose polarization can be measured, summing over all virtual photon energies.

E_{beam} (GeV)	Triggers (M)	Λ	Σ^0
2.5	910	39000	21000
3.1	1000	36000	18500
4.2	766	22000	10500

Table 4: Comparison of the number of ground-state hyperons whose polarization can be measured in each of the data sets collected with highly polarized electron beams with the CLAS detector during the 1998, 1999, and 2000 E1 running periods.

Figs. 16 and 17 show some of our preliminary beam-recoil double-polarization analysis results at 4.2 GeV to indicate the statistical quality of the data set. Fig. 16 shows P_L' and P_T' as a function of W. These data have been summed over all Q^2 and $d\Omega_K^*$, and still result in absolute statistical uncertainties in the polarization of between ± 0.08 and ± 0.30 with 100 MeV wide bins in W. In this analysis, the important kinematic variables to study include not only W, but also Q^2 and $\cos\theta_K^*$. In studies of N^* production in the intermediate state, bins as narrow as possible in W are essential to reduce the number of overlapping states. In studies of t-channel meson exchange, it is important to study the polarization in fine bins of $\cos\theta_K^*$. In understanding the form factors of the contributing intermediate state hadrons, narrow bins in Q^2 are desirable. In order to have a more substantive impact on this field, our observables must be studied over all of the related kinematic variables with finer binning than is possible with the existing data sets. In our current beam time request, we have planned for an additional 10 days of running at 3.2 GeV. Given the current performance of CLAS, this will allow us to at least double the number of bins in W and $\cos\theta_K^*$, while at the same time, reducing the absolute uncertainties on the polarization to ±0.05 to ±0.20.

In contrast to the relatively mild energy dependence, we see a forward-backward asymmetry in the polarization as a function of the kaon center-of-mass angle (see Fig. 17). This effect has been seen in the induced hyperon polarization data from both photoproduction and electroproduction [43, 44, 45]. This basic trend can be qualitatively explained on the basis of a virtual photon-quark interaction [46], and has also been seen in exclusive high-energy hadron-hadron collisions at CERN [47]. A more detailed study with our CLAS data in finer bins of W with at least double the number of bins in $\cos\theta_K^*$ will allow us to determine if the shape of the asymmetry is universal, independent of W.

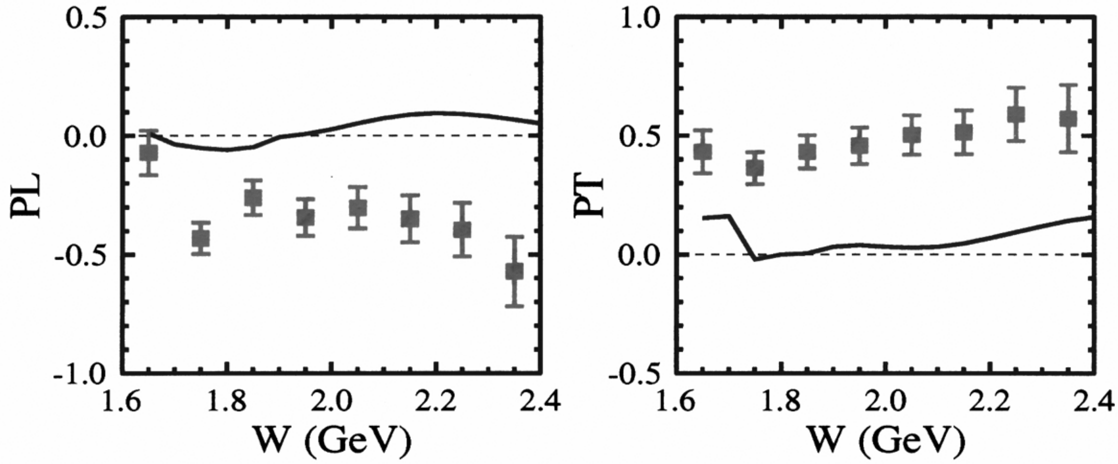


Figure 16: Preliminary CLAS hyperon transferred polarization observables P_L' and P_T' at 4.247 GeV as a function of W. Data are summed over Q^2 and $d\Omega_K^*$. The curves correspond to a hadrodynamic calculation [42].

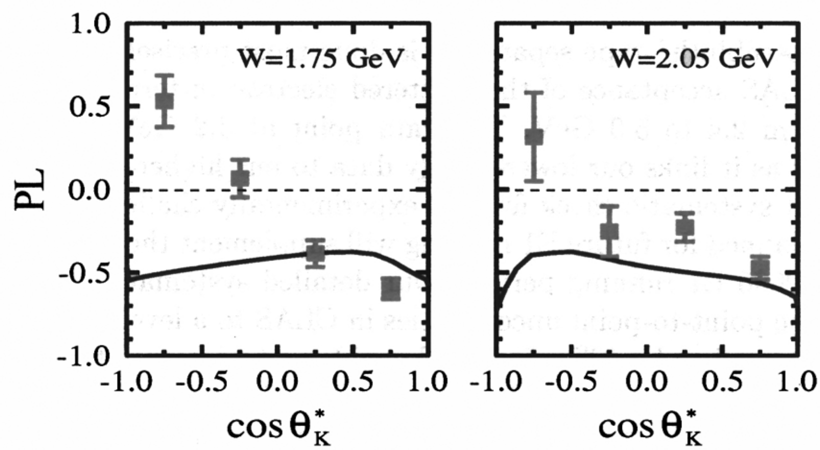


Figure 17: Preliminary CLAS hyperon transferred polarization P_L' at 4.247 GeV as a function of $\cos\theta_K^*$. Data are summed over Q^2 and all relative angles Φ^* between the electron and hadron scattering planes. The curves correspond to a hadrodynamic calculation [42].

Our analysis of CLAS data indicate that neither the energy nor the angular dependence of the polarization data can be reproduced by the existing hadrodynamic model descriptions.

However, with the coarse binning and sizeable statistical uncertainties, it is not possible to fully address whether the models are missing some essential underlying elements of the dynamics or are based on the wrong degrees of freedom. Additional data is crucial to this measurement program.

A second area where additional data will prove important is our program to separate the longitudinal and transverse structure functions σ_L and σ_T for the ground-state hyperons. At the present time there are only two published experimental results attempting to perform an L/T separation for kaon electroproduction, and both were done at very low t [48, 49]. The data from this experiment will increase the t range of the extraction up to nearly 2 (GeV/c)^2, while also spanning W from threshold up to 2.4 GeV and Q^2 up to 3 (GeV/c)^2.

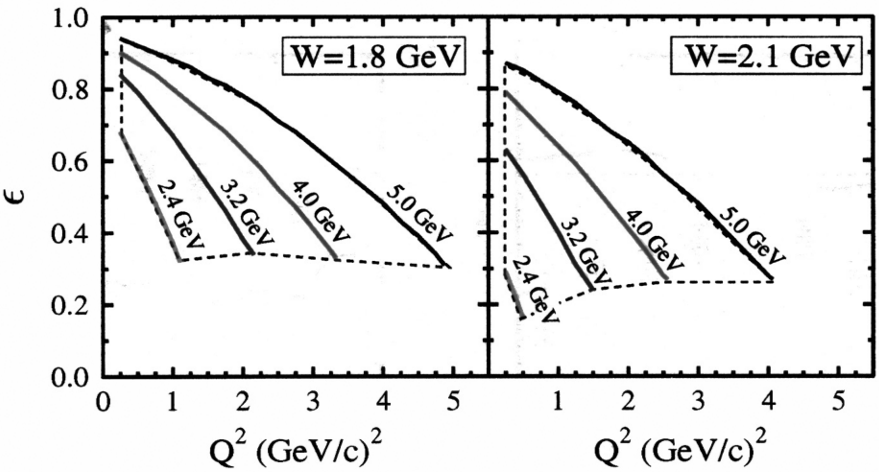


Figure 18: CLAS acceptance (within dashed outline) of the scattered electron in terms of ϵ vs. Q^2 at W=1.8 GeV and 2.1 GeV for beam energies in the range from 2.4 to 5.0 GeV.

With CLAS, σ_L and σ_T are extracted by comparing measurements at different values of beam energy, and thus different values of the polarization parameter ϵ, while keeping Q^2, W, and t fixed. This "Rosenbluth"-type separation is done most precisely for large ϵ coverage. Fig. 18 shows the CLAS acceptance of the scattered electron in terms of ϵ and Q^2 for our E1 beam energies from 2.4 to 5.0 GeV. The data point at 3.2 GeV represents a critical point to measure well as it links our lower-energy data to our higher-energy data, and thus provides an important systematic check for this experimentally challenging procedure. The 3.2 GeV beam time planned for future E1 running will supplement the 3.1 GeV running that occurred during the 2000 E1 running period. Our detailed systematic studies have shown that we can control the point-to-point uncertainties in CLAS to a level of 6% with an overall scale uncertainty estimated to be 10%. This will enable us to measure the ratio $R = \sigma_L/\sigma_T$ with a fractional error in the range from 15% to 50% depending on the kinematic bin studied.

A final aspect of our measurement program desperately in need of a better statistical data set is the study of $K^{0*}(892)$ production [50]. The electroproduction of K^{0*} mesons provides an added dimension to the strangeness production program at CLAS as any successful model of strangeness production should predict both K and K^* production processes. The K^*, a vector meson, is an essential ingredient in theoretical models of kaon photoproduction, where the K^*NY coupling in the t-channel is currently treated as a free parameter. Directly measuring K^* production will constrain this ambiguity. Perhaps more interesting is that K^{0*}

production is predicted to go predominantly through the $N(2220)$ and $N(2250)$ resonances, which are well known from π-N scattering. The branching ratios of these N^* resonances into strangeness channels is currently a totally open question [51]. Preliminary electroproduction data from CLAS (see Fig. 19) show a strong peak in the W spectrum corresponding to these resonances. However, the statistics are poor, amounting to only a few hundred counts. Additional data are needed to accurately measure cross sections and branching ratios.

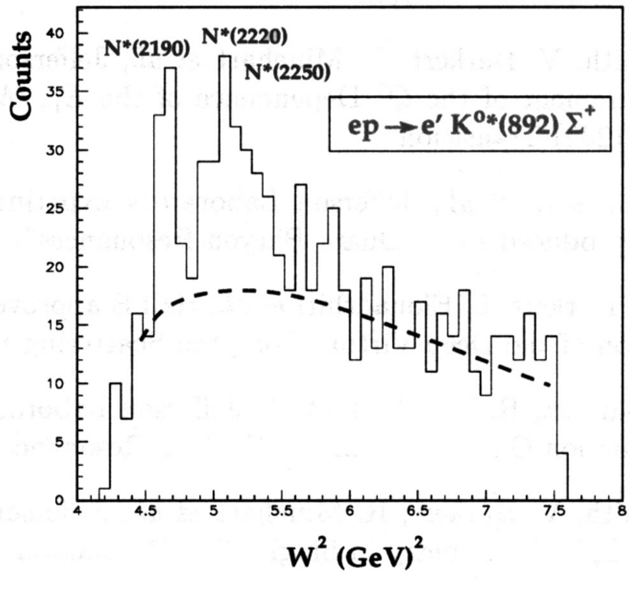


Figure 19: Reconstructed W^2 spectrum from analysis of 4.247 GeV CLAS data for K^{0*}-Σ^+ final states summed over the range of Q^2 from 0.75 to 1.25 $(\mathrm{GeV/c})^2$. The curve shows the estimate of background from pion misidentification.

5.3 Beam Time Request

We expect that our request of 10 days of running at 3.2 GeV, given the current performance of CLAS, will allow us to improve our overall hyperon sample at 3 GeV by a factor of three to four when combined with the existing 3.1 GeV data from E1D. This will have substantial impact on our measurements of hyperon polarization and their theoretical interpretation within the resonance region. The data will also be critical for our measurement program of vector kaon production. This additional beam time we feel is extremely important to these measurements and their subsequent usefulness to the community. In addition, this beam time at 3.2 GeV will both improve the precision of our Rosenbluth separation of the σ_T and σ_L structure functions, and extend its range over the full resonance region while spanning an increased range in Q^2.

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[7] H. Egiyan, V. Burkert, R. Minehart *et al.*, Jefferson Laboratory experiment E89-037, "Single π^+ Production Off Protons in the Nucleon Resonance Region".

[8] K. Joo, L.C. Smith, V. Burkert, R. Minehart *et al.*, Jefferson Laboratory experiment E89-042, "Beam Spin Asymmetry in Single Pion Production".

[9] R. Feuerbach, G. Niculescu, K. Hicks, M. Mestayer *et al.*, Jefferson Laboratory experiment E93-030, "Electroproduction of $K^+\Lambda$ and $K^+\Sigma^0$ Off Protons".

[10] D.S. Carman, B.A. Raue *et al.*, Jefferson Laboratory experiment E99-006, "Polarization Observables in $K^+\Lambda$ and $K^+\Sigma^0$ Electroproduction Off Protons".

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6 Appendix A : Experiments in the E1 Run Group

1. E89-037: *"Electroproduction of the P_{33}(1232) Resonance"*, Spokespersons: V. Burkert and R. Minehart. Thesis student: H. Egiyan.

2. E89-038 : *"Measurements of $p(e,e'\pi^+)n$, $p(e,e'p)\pi^0$, and $n(e,e'\pi^-)p$ in the Second and Third Resonance Regions"*, Spokespersons: V. Burkert and R. Minehart.

3. E89-039 : *"Amplitudes for the S_{11}(1535) and P_{11}(1710) Resonances from an $ep \rightarrow e'p\eta$ Experiment"*, Spokespersons: S.A. Dytman and J.A. Mueller. Thesis student: R.A. Thompson.

4. E89-042 : *"Measurement of the Electron Asymmetry in $p(\vec{e},e'p)\pi^0$ and $p(\vec{e},e'\pi^+)n$ in the Mass Region of the $\Delta(1232)$ for $Q^2 < 2$ (GeV/c)^2"*, Spokespersons: V. Burkert, R. Minehart, and L.C. Smith.

5. E89-043 : *"Measurement of the Electroproduction of the $\Lambda(1116)$, $\Lambda(1520)$, and $f_0(892)$ via the K^+K^-p and $K^+\pi^-p$ Reactions"*, Spokespersons: L. Dennis and H. Funsten. Thesis student: S. McAleer.

6. E91-002 : *"The Study of Excited Baryons at High Momentum Transfer with the CLAS Spectrometer"*, Spokesperson: P. Stoler. Thesis student: M. Ungaro.

7. E91-024 : *"Search for Missing Resonances in the Electroproduction of ω Mesons"*, Spokespersons: V. Burkert, H. Funsten, D. Manley, and B.A. Mecking. Thesis student: A. Coleman.

8. E93-006 : *"Two Pion Decay of Electroproduced Light Quark Baryon Resonances"*, Spokespersons: M. Ripani and V. Burkert.

9. E93-012 : *"Electroproduction of Light Quark Mesons"*, Spokesperson: M. Kossov. Thesis student: V. Serov.

10. E93-022 : *"Measurement of the Polarization of the $\phi(1020)$ in Electroproduction"*, Spokespersons: H. Funsten, P. Rubin, and E.S. Smith. Thesis student: K. Loukachine.

11. E93-030 : *"Measurement of the Structure Functions for Kaon Electroproduction"*, Spokespersons: M.D. Mestayer and K.H. Hicks. Thesis student: R. Feuerbach.

12. E93-043 : *"Measurement of the $\Delta\Delta$ Component of the Deuteron by Exclusive Quasi-elastic Electron Scattering"*, Spokesperson: B. Quinn.

13. E94-005 : *"Determination of the $N-\Delta$ Axial Vector Transition Form Factor $G_A^{N-\Delta}$ from the $ep \rightarrow e'\Delta\pi^-$ Reaction"*, Spokespersons: L. Elouadrhiri, D. Heddle.

14. E95-003 : *"Measurement of K^0 Electroproduction"*, Spokespersons: R.A. Schumacher, K. Dhuga.

15. E99-006 : *"Polarization Observables in the* $^1H(\vec{e}, e'K^+)\vec{\Lambda}$ *Reaction"*, Spokespersons: D.S. Carman, K. Joo, L.H. Kramer, B.A. Raue. Thesis student: R. Nasseripour.

16. CAA-2000-1 : *"K^* Electroproduction from the Proton"*, Spokesperson: K.H. Hicks. Thesis student: A. Wiseberg.

17. CAA-2001-1 : *"Deep Virtual Compton Scattering at 4 to 5 GeV with CLAS"*, Spokespersons : V. Burkert, L. Elouadrhiri, and S. Stepanyan.

7 Appendix B : E1 Related Talks Given at Conferences

1. Daniel S. Carman, "Kaon Electroproduction Experiments Off the Proton", APS Meeting, Washington D.C., April 27 - May 1, 2001.

2. Kyungseon Joo, "Single Pion Beam Asymmetry Measurements in the $\Delta(1232)$ resonance region using CLAS", NSTAR2001, Mainz, Germany, March 7-10, 2001.

3. Jim Mueller, "Photo and Electroproduction of η Mesons", NSTAR2001, Mainz, Germany, March 7-10, 2001.

4. Brian Raue, "Kaon Electroproduction and Λ Polarization Observables Measured with CLAS", NSTAR2001, Mainz, Germany, March 7-10, 2001.

5. L. Cole Smith, "Pion Electroproduction Using CLAS", NSTAR2001, Mainz, Germany, March 7-10, 2001.

6. Volker Burkert, "Hadron Physics at CEBAF, CLAS Results", Structure of Hadrons, Kleinwalsertal, Austria, January, 2001.

7. Marco Ripani, "N* Results from CLAS", Workshop on Relativistic Dynamics and Hadron Structure, Trento, Italy, Nov. 6-17, 2000.

8. Kyungseon Joo, "Single π Electroproduction in $\Delta(1232)$ from CLAS at Jefferson Lab", SPIN 2000, Osaka, Japan, Oct 6-21, 2000.

9. Steve Barrow, "Electroproduction of the $\Lambda(1520)$ Hyperon", Division of Nuclear Physics, Williamsburg, VA, Oct 4-7, 2000.

10. Daniel S. Carman, "Hyperon Double-Polarization Observables from CLAS for the $p(e, e'K+)Y$ Reaction", Division of Nuclear Physics, Williamsburg, VA, Oct 4-7, 2000.

11. Latifa Elouadrhiri, "Baryon Transition Form Factors Measurements with CLAS", Division of Nuclear Physics, Williamsburg, VA, Oct 4-7, 2000.

12. Kyungseon Joo, "Single π^0 Electroproduction in the $\Delta(1232)$ Resonance Region Using CLAS at Jefferson Lab", Division of Nuclear Physics, Williamsburg, VA, Oct 4-7, 2000.

13. Gabriel Niculescu, "Interference Structure Functions in Kaon Electroproduction", Division of Nuclear Physics, Williamsburg, VA, Oct 4-7, 2000.

14. Marco Battaglieri, "Activity in Hall B at Jefferson LAB", Clustering Phenomena in Nuclear Physics, St. Petersburg, Russia, June 14-17, 2000.

15. Marco Anghinolfi, "Overview of Hall B Experiment at JLab", Symposium on The Gerasimov-Drell-Hearn Sum Rule and the Nucleon Spin Structure in the Resonance Region, Mainz, Germany, June 14-17, 2000.

16. Marco Ripani, "Selected Results from Hall B", 9th International Conference on Nuclear Reaction Mechanisms, Villa Monastero, Varenna, Italy, June 5-9, 2000.

17. Kyungseon Joo,"Single pion electroproduction from CLAS", CIPANP 2000 - 7th Conference on the Intersections of Particle and Nuclear Physics, Quebec City, Quebec, Canada, May 22-28, 2000.

18. Jim Mueller, "Eta Electroproduction in the $S_{11}(1535)$ Region with CLAS", CIPANP 2000 - 7th Conference on the Intersections of Particle and Nuclear Physics, Quebec City, Quebec, Canada, May 22-28, 2000.

19. Daniel S. Carman, "Hyperon Electroproduction Experiments in Hall B at Jefferson Laboratory", Strange Quarks in Hadrons, Nuclei, and Nuclear Matter, Ohio University, Athens, OH, May 12-13, 2000.

20. Hovanes Egiyan, "Electroproduction Experiments Using the CLAS at JLab", APS Meeting, Long Beach, CA, May 2000.

21. Konstantin Loukachine, "Electroproduction of the $\phi(1020)$ Vector Meson at 4 GeV", APS Meeting, Long Beach, CA, May 2000.

22. Simeon McAleer, "Preliminary Results of Lambda(1116) Recoil Polarization in Electroproduction", APS Meeting, Long Beach, CA, May 2000.

23. Reinhard Schumacher, "Status of Strangeness Production Experiments at JLab", Workshop on Open Strangeness at MAMI C, Mainz, Germany, March 16,17, 2000.

24. Volker Burkert, "Recent Results from the N* Program at Jlab", 16th International Conference on Few-Body Problems in Physics, Taipei, Taiwan, March 6-10, 2000.

25. Latifa Elouadrhiri, "Single Pion Electroproduction in the $\Delta(1232)$ from CLAS Data at Jefferson Lab", 16th International Conference on Few-Body Problems in Physics, Taipei, Taiwan, March 6-10, 2000.

26. Franz Klein, "Search for Resonance Contributions in the Reaction Channel $ep \to e'p\omega$ with CLAS at Jefferson Lab", 16th International Conference on Few-Body Problems in Physics, Taipei, Taiwan, March 6-10, 2000.

27. Elton Smith, "Recent Results from Jefferson Laboratory", International Conference on Quark Nuclear Physics, Adelaide Australia, Feb 21-25, 2000.

28. Mac Mestayer, "Study of Excited Baryon Decays to Strangeness Using the CLAS Detector", NSTAR 2000, The Physics of Excited Nucleons, Jefferson Lab, Newport News, Feb. 16-19, 2000.

29. Robert Feuerbach, "Preliminary Results for Λ and Σ^0 Electroproduction at CLAS", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

30. Kyungseon Joo, "Single π^0 Electroproduction in the $\Delta(1232)$ Resonance Region Using CLAS", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

31. Kui Young Kim, "η Electroproduction in the $S_{11}(1535)$ Resonance Region", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

32. Franz Klein, "Electro- and Photoproduction of ω Mesons with the CLAS Detector", APS Division of Nuclear Physics Meeting, Asilomar, CA,October 13-17, 1999.

33. Jim Mueller, "The N* Program with CLAS", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

34. Marco Ripani, "Two Pion Electroproduction with the CLAS Detector at Jefferson Laboratory", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

35. Mauro Taiuti, "Baryon Resonance Transition Form Factors", APS Division of Nuclear Physics Meeting, Asilomar, CA, October 13-17, 1999.

36. Marco Battaglieri, "Rho Photoproduction at High t Using CLAS", Electromagnetic Interactions With Nucleons and Nuclei Probing Hadrons and Nuclei at High Energies, Santorini, Greece, October 4-5, 1999.

37. Reinhard Schumacher, "Strangeness Production at CEBAF", Workshop on Flavor Production, Santorini, Greece, October 4-5, 1999.

38. Volker Burkert, "Recent Results from Jefferson Lab", Erice School, Erice, October, 1999.

39. Elton Smith, "Physics with CLAS", Latin American Workshop on Nuclear and Heavy Ion Physics, Bogota, Colombia, September 13-17, 1999.

40. Mauro Taiuti, "N* Physics with CLAS", Bosen School, Bosen, Germany, September, 1999.

41. Steve Dytman, "Meson Production Experiments with Electromagnetic Beams using CLAS", MENU99: Meson-Nucleon Physics and the Structure of the Nucleon, PSI, Switzerland, Aug 20-26, 1999.

42. Steve Dytman, "Studies of N* Resonances with Electromagnetic and Pion Probes", Leptons and Hadrons as Complementary Probes of Strong QCD, Juelich, Germany, June 17-19, 1999.

43. Volker Burkert, "Study of the Nucleon Structure Using Electromagnetic Probes in the Few GeV regime", PANIC99: XV International Conference on Particles and Nuclei, Uppsala, Sweden, June 10-16, 1999.

44. Joe Manak, "Electro- and Photoproduction of $\omega(738)$ Mesons Using CLAS at Jefferson Lab", PANIC99: XV International Conference on Particles and Nuclei, Uppsala, Sweden, June 10-16, 1999.

45. Mac Mestayer, "Hyperon Electroproduction with CLAS", PANIC99: XV International Conference on Particles and Nuclei, Uppsala, Sweden, June 10-16, 1999.

46. Marco Ripani, "Two Pion Electroproduction", PANIC99: XV International Conference on Particles and Nuclei,Uppsala, Sweden, June 10-16, 1999.

47. Mauro Taiuti, "First Preliminary Results from CLAS", Perspectives in Hadronic Physics, Trieste, Italy, May 10-14, 1999.

48. Alan Coleman, "Electroproduction of $\omega(738)$ Mesons Using CLAS at Jefferson Lab", APS Centennial Celebration, Atlanta, GA, March 20-26, 1999.

49. Hovanes Egiyan, "Single π^+ Electroproduction Experiments Using CLAS at Jefferson Lab", APS Centennial Celebration, Atlanta, GA, March 20-26, 1999.

50. Robert Feuerbach, "Kaon Angular Distribution for Λ and Σ^0 Electroproduction", APS Centennial Celebration, Atlanta, GA, March 20-26, 1999.

51. Kyungseon Joo, "Single π^0 Electroproduction with CLAS", APS Centennial Celebration, Atlanta, GA, March 20-26, 1999.

52. Gabriel Niculescu, "Kinematic Dependence of Σ/Λ Ratio in Kaon Electroproduction", APS Centennial Celebration, Atlanta, GA, March 20-26, 1999.

53. Steve Dytman, "Initial Results of Meson Electroproduction Experiments at CLAS", APS Division of Nuclear Physics Meeting, Santa Fe, NM, Oct. 28-31, 1998.

54. Steve Barrow, "Electroproduction of $\Lambda(1115)$ and $\Lambda(1520)$ via the Reaction $e + p \rightarrow e + K^+ + (p + K^-)$ and $e + p \rightarrow e + K^+ + (p + \pi^-)$", APS Division of Nuclear Physics Meeting, Santa Fe, NM, Oct. 28-31, 1998.

55. K. Loukachine, "ϕ Meson Electroproduction at CEBAF (JLab)", APS Division of Nuclear Physics Meeting, Santa Fe, NM, Oct. 28-31, 1998.

56. Richard Thompson, "A New Measurement of $p(e, e'p)\eta$ Experiments at CLAS", APS Division of Nuclear Physics Meeting, Santa Fe, NM, Oct. 28-31, 1998.

57. Jim Mueller, "η Electroproduction in the S11(1535) Region with CLAS", Baryons '98, University of Bonn, Bonn, Germany, Sept. 22-26, 1998.

58. Marco Battaglieri, "Preliminary Angular Distribution in π^0 Electroproduction in the Δ Region at $Q^2 > 0.5$ (GeV)^2", Baryons '98, University of Bonn, Bonn, Germany, Sept. 22-26, 1998.

59. Latifa Elouadrhiri, "Determination of the N-Δ Axial Vector Transition Form Factor from the $ep \rightarrow e'\Delta^{++}\pi^-$ Reaction", Baryons '98, University of Bonn, Bonn, Germany, Sept. 22-26, 1998.

60. Franz Klein, "Search for Missing Resonances in $\gamma^* p \rightarrow X \rightarrow \Omega p$", Baryons '98, University of Bonn, Bonn, Germany, Sept. 22-26, 1998.

61. Volker Burkert, "Recent Results from CLAS at the Jefferson Laboratory", Gordon Conference on Photonuclear Reactions, Tilton, NH, July 26-31, 1998.

62. Ralph Minehart, "Review of the N-star Program at CLAS", Workshop on Electron Nucleus, Elba, June 22-26, 1998.

63. Volker Burkert, "Electromagnetic Excitation of Baryon Resonances and the CLAS N* Program", N* Workshop, Trento, May, 1998.

64. Kyungseon Joo, "Single Pion Electroproduction Using CLAS", N* Workshop, Trento, May, 1998.

65. Marco Ripani, "Baryon Resonances in the Double Pion Channel at Jefferson Lab", N* Workshop, Trento, May, 1998.

66. Reinhard Schumacher, "K Meson Photo- and Electro-Production with CLAS at JLab", N* Workshop, Trento, Italy, May, 1998.