

CEBAF Program Advisory Committee Ten Proposal Cover Sheet

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☐ New Proposal Title:

☒ Update Experiment Number:

Hall B

E1

running
period.

☐ Letter-of-Intent Title:

Contact Person

Name:

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Information given in the
individual updates.

Experimental Hall: B

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Overview of e1 Run Period Experiments

The experimental updates contained in this section are grouped together because of very similar running conditions rather than unified physics; therefore, this is generically labelled the 'e1 run period'. All of these experiments will use an electron beam and unpolarized proton and/or deuteron targets. Many of the experiments also have a common physics theme of studying N^* production; the beam time was originally awarded for N^* experiments.

Listing the physics goals for these experiments in many ways highlights the evolution of nuclear physics as a discipline. Our concept of the proton has evolved from a point charge, to an extended charge and magnetization distribution, to a complex bound state of quarks and gluons. Experiments 89-037, 89-038, 89-039, 89-042, 89-043, 91-002, 91-024, 93-006, 93-030 and 94-042 are part of the N^* program and aim to learn about baryon structure, including that of strange baryons. Experiments 89-043, 93-012, and 93-022 will use a proton target as a source of mesons and will study the microscopic structure of mesons. Experiment 93-043 will use a deuteron target to learn about the deuteron, specifically its $\Delta\Delta$ component. This is of course a few-nucleon study of quark dynamics.

Another common theme is the revisiting of old topics. Quite often, these experiments were motivated by previous work in what was once considered high-energy physics; however, the previous studies were far from complete when the field moved on to yet higher energies. The interesting unifying group structures were discovered, but the study of internal dynamics was just begun. The quark model was not widely believed, so theory work was largely confined to nonrelativistic quark models. The advantages for the studies discussed in these updates are significant. A modern large acceptance spectrometer will be applied to these reactions for the first time, making the collection of large amounts of data feasible. This should make extraction of interesting physics information far more reliable than in the past. In addition, physicists now believe in the quark model, thus making the technically complicated theory projects worthwhile.

When the experiments are run, the overlapping beam requirements make these experiments natural partners. For the N^* experiments, sharing the same beam for many measurements will significantly decrease systematic errors when theory analyses are undertaken. The N^* collaborators have viewed the measurements in this way from the time the experiments were originally proposed. The other experiments have similar beam requirements and will use overlapping time as much as possible. The proposers have agreed to a schedule that will require 124 days to complete. The main body of running will come according to the plan proposed for the N^* experiments, with 36 days approved by previous PACs. Because of conditions particular to experiments 93-022, 93-030, and 93-043, there must also be shorter time periods of length 15, 8, and 16 days, respectively, when these experiments will be run. They will set the toroid magnet to the opposite field polarity, or at a different field strength (when low-energy particles must be detected). In that case, acceptance is strongly dependent on details of the magnetic field.

| proposal | spokespersons | title |
|----------|-----------------------------------|---|
| 89-037 | Burkert, Minehart | Electroproduction of the Delta Resonance |
| 89-038 | Minehart, Burkert, Gai | Measurement of the $p(e, e'\pi^+)n$, $p(e, e'p)\pi^0$, and $d(e, e'\pi^-)pp$ in the 2nd and 3rd Resonance Region |
| 89-039 | Dytman, Giovanetti | Amplitudes for the $S_{11}(1535)$ and $P_{11}(1710)$ Resonances from a $p(e, e'p)\eta$ Experiment |
| 89-042 | Burkert, Minehart | Measurement of the Electron Asymmetry in $p(e, e'p)\pi^0$ and $p(e, e'\pi^+)n$ in the Mass Region of the Delta Resonance for $Q^2 \leq 2 \text{ GeV}^2$ |
| 89-043 | Dennis, Funsten, Gilfoyle | Measurements of the Electroproduction of the Λ , $\Lambda^*(1520)$ and $f_0(975)$ via the $K^+\pi^-p$ and K^+K^-p Final States |
| 91-002 | Stoler, Burkert, Taiuti | Excited Baryon Form-Factors at High Momentum Transfer |
| 91-024 | Funsten, Burkert, Manley, Mecking | Search for "Missing" Resonances in the Electroproduction of ω Mesons |
| 93-006 | Ripani, Burkert | Two Pion Decay of the Electroproduced Light Quark Baryon Resonances |
| 93-012 | Kossov | Electroproduction of Light Quark Mesons |
| 93-022 | Funsten, Rubin, Smith | Measurement of the Polarization of the $\phi(1020)$ in Electroproduction |
| 93-030 | Mestayer, Hicks | Measurement of the Structure Functions for Kaon Electroproduction |
| 93-043 | Quinn | Measurement of the $\Delta\Delta$ Component of the Deuteron by Exclusive Quasielastic Electron Scattering |
| 94-042* | Elouadrhiri, Heddle, Hicks, Li | Determination of the $N\Delta$ Axial Vector Transition Form Factor $G_A^{N\Delta}$ from the $ep \rightarrow e'\Delta^{++}\pi^-$ Reaction |

* This experiment is not included in the enclosed updates because it was evaluated by the last PAC.

e1 Run Period Management

The collaborations seeks successful operation of CLAS and the accumulation of high quality data on the optimum physics issues. In another document, the CLAS collaboration suggests the establishment of 2 collaboration-wide positions to achieve the best balance of these 2 goals. The Chief of Operations (COP) will have the final say in all technical issues on the floor, and technical issues must have priority over physics issues with a detector as complicated and expensive as CLAS. The Experimental Coordinator (ECO) would be chosen by the Coordinating Committee to provide expert advice on the relevant physics issues for the particular run period and would normally be one of the spokespersons. Here, we propose the establishment of a Run Plan Committee that represents the e1 run period spokespersons in decisions related to the running of our experiments.

There are 13 experiments and 25 spokespersons sharing beam time in this run period. Any decision making process during the running of the experiment that is truly democratic would be unmanageable due to the unwieldy size of the group. On the other hand, all spokespersons need to have a voice in determining the goals of each run period and in decision making on the experimental floor. The best system seems to be a representative one, where a small committee of dedicated persons is chosen to implement a predetermined plan for a specific run period. All spokespersons make a run plan before the run period begins that lists the physics priorities. The Run Period Committee makes final decisions during the experiment in conjunction with the COP and ECO. In all cases, the Run Period Committee must make reasonable efforts to understand the important issues for each specific experiment and elicit opinions of individual spokespersons. Otherwise, we run the risk of destroying the collegiality that so far has characterized our group.

We propose a Run Period Committee that reflects the possible differing viewpoints of the experiments. We propose a two person committee that is chosen by the spokespersons; the effective working committee would contain three people since the function of the ECO is very similar. These people would serve terms of 1 year, and each individual could serve 2 consecutive terms. The history of this group of experiments is that the beam time was initially allotted to the proposers of the baryon structure experiments. Those spokespersons are still the largest subgroup of the experiments discuss here and we feel that that physics is a primary focus of this run period. Thus, one of the Run Plan Committee persons will be a member of the N* Collaboration and the other person will not be a member of that collaboration. Skills desired for this committee are broad because decisions regarding a wide variety of technical and physics issues might be required. Membership of both CEBAF and university physicists is desirable. Members of the committee should be in residence at CEBAF during a significant portion of the run period.

REQUEST TO PAC10 FOR RATING OF e1 run period

There are a large number of proposals in this run period and many of them have significant overlap. For example, the N* Collaboration proposed experiments that must be run together to take advantage of decreased systematic errors resulting from use of the same beam time; thus, these experiments are naturally aligned toward a common goal. We feel that while we are *all* seeking the larger goal of describing the structure of the nucleon, our

experiments can be divided usefully into 3 groups. These groups share common physics issues that have direct consequence in the running of the experiment and in the analysis of the data. The groups are baryon structure (89-037, 89-039, 89-042, 89-043, 91-002, 93-006, 93-030, and 94-042), meson structure (89-043, 93-013, and 93-022), and deuteron structure (93-043).

We propose that the PAC rate these experiments according to the above classifications. When a specific run plan is devised, a number of factors must be factored into it. The ratings of the PAC will be the primary input about quality of physics. Technical issues in such a large detector will always be important and can seldom be decided far in advance because equipment failures and experimental background issues can seldom be anticipated. This run plan will be determined by the spokespersons to optimize output according to physics and technical considerations. The Run Plan Committee will have the job to implement the plan with continuing input from members of the collaboration.

N* Collaboration Updates for Experiments

Enclosed are the updates for CLAS experiments proposed by members of the N* collaboration. All the experiments will run together and will benefit greatly from a common analysis. Therefore, it is logical to present them together. Since many of the issues are shared, we have also written 2 general documents that give an overview of important developments. The order is

List of Collaboration Physicists
Analysis Software of the N* Program
Theory Issues for N* Experiments
89-037
89-038
89-039
89-042
89-043
91-002
91-024
93-006
93-030

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Theory Issues for N^* Experiments

The experimental goal of our program is to provide high quality data describing the many varied N^* states while theory will be required to produce models for the wave functions of these states and calculations of relevant observables. At that point, the ultimate goal of distinguishing between various pictures of the nonperturbative regime of QCD can be addressed. Although not much progress has been made in experimental studies of N^* resonances since our experiments were originally approved in 1989, a large number of theorists have been clarifying old issues and pursuing new directions. In anticipation of the large quantities of data to come from CEBAF N^* experiments, theorists have been improving models and exploring the role of QCD. These recent efforts can be put into 3 broad, overlapping categories- improving the dynamic aspects of N^* photo- and electroproduction, investigations of the important degrees of freedom in baryons, and searching for links to high energy phenomena where QCD effects are more readily apparent.

Calculations involving N^* resonances (or any light quark hadron) are difficult and techniques for including various dynamical effects must be explored before confrontations with QCD can be made. If experiments are able to produce data of significantly higher quality than previous efforts, comparable machinery must be set up to extract quantities of interest. This subject is at the interface of theory and experiment, requiring input from both. One major goal of this work is to make model independent fits for $\gamma N \rightarrow N^*$ interactions with the same or greater rigor as was applied to $\pi N \rightarrow N^*$ in the 1970's and 1980's (such as Karlsruhe and CMU-LBL analyses). Present workers have the advantage of far superior computing capabilities which will be required to handle the large variety of final states better than was done in the πN studies referenced above. This project requires unitary self-consistent calculations of the many channels that can couple to the resonances- e.g., γN , πN , ηN , ρN , ωN , $\pi\pi N$. The efforts towards a model-independent fitting analysis by members of the N^* collaboration are covered in an accompanying document. Theorists are contributing to this effort by providing quark model calculations^[1] for the coupling of resonances to various meson+nucleon final states.

Another important direction for theory is in explorations of the role of relativity. The need for relativity can occur in different ways- in the baryon wave function and in the dynamics of the interaction. Many early calculations were done using the nonrelativistic quark model (NRQM). Despite its significant empirical successes, it has also been criticized for missing the important fact that the quarks are expected to have relativistic velocities. Although the success of the NRQM is surely telling us something very interesting, a more full relativistic treatment will be required to understand the importance of the empirical conclusions. The effects of relativity are important in the final state because both the excited baryon and its decay products have large velocity in experiments. It has been found^[2] that these effects are important for describing recoiling low-mass states such as the proton, $P_{33}(1232)$ and the Roper ($P_{11}(1440)$). Numerous papers^[3] report better description of the nucleon form factors at higher Q^2 with proper relativity even when the wave function has been simplified for numerical convenience. New approaches for describing the quark binding in hadrons, such as the distributed string model^[4] have been developed, giving form factor calculations which are also very different from the harmonic oscillator description.

Finding the important degrees of freedom in baryons is a fascinating subject that

must also begin with the NRQM. The success of its assumption that the quarks are the main degrees of freedom appears quite surprising in light of what QCD prescribes. In the nonperturbative regime, the effects of gluons and $q\bar{q}$ pairs should be quite obvious. None of these issues can be explored in detail without significantly more data, but the questions can be phrased in interesting ways based on recent work. There are indications that states such as $P_{11}(1440)$ might be hybrid states, i.e. have strong admixtures of $qqqg$ in the wave function.^[5] Are these states really hybrid? Can the data distinguish between normal and hybrid states? One paper suggests that longitudinal electroproduction is one of the few ways of disentangling these interesting states.^[6]

The NRQM predicts many N^* states beyond those already found. Some models, such as the diquark-quark cluster model^[7] predict a fewer number of excited states due to the reduced numbers of degrees of freedom. However, is it possible that these states are weakly coupled to πN and will be readily apparent in high quality electroproduction experiments?^[8]

There have been many studies of QCD in high energy experiments. Although the successes of QCD are numerous, there are also many surprises that are not yet understood. For example, deep inelastic scattering and spin structure function results have shown that the valence structure is governed to a large extent by degrees of freedom other than quarks. The spin structure issues have a natural place in low energy phenomena in the Gerasimov-Drell-Hearn (GDH) sum rule. A number of theorists are studying whether the same models that successfully describe high energy data can be evolved to apply at CEBAF energies.^[9] The role of N^* resonances in these issues will surely be important, but is not yet understood.

Many people feel an important test of any low energy QCD model is to find its link with perturbative QCD. Although there is very little relevant data, there are already examples of how N^* resonances behave quite differently when Q^2 gets large. The $P_{33}(1232)$ state is seen to be weakly excited at $Q^2 \sim 3 \text{ GeV}^2/c^2$, behavior that is tentatively explained in perturbative QCD models. Similar models predict the E_{1+} multipole which is very weakly excited at low Q^2 will become equal in strength to the M_{1+} at high Q^2 . A related issue has been in deciding when high Q^2 (i.e. high enough that perturbative QCD is important) has been reached. There is a lively discussion on the role of hard vs. soft QCD processes^[10] that seems resolvable only with new data.

There have also been important advances in calculations that are much more sophisticated than the constituent quark model. Roberts and Williams^[11] presently do calculations of meson structure with empirical self-consistent gluon and quark propagators. This work is presently being extended to baryons. Weingarten and collaborators^[12] have published successful lattice QCD calculations of masses of the lightest baryons. Leinweber and collaborators^[13] are actively applying lattice QCD to nuclear physics problems. They have published calculations of baryon magnetic moments and the $N \rightarrow \Delta$ M1 transition that are in qualitative agreement with data.

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Update of Experiment: E-89-037:
Electroproduction of the Delta Resonance

and E-89-042:
Measurement of the Electron Asymmetry in $p(e,e'p)\pi^0$
and $p(e,e'\pi^+)n$ in the Mass Region of the
Delta Resonance for $Q^2 \leq 2 \text{ GeV}^2$

Spokespersons: V.D. Burkert, R. Minehart

Proposed measurements:

Electroproduction of neutral and charged pions via the $\bar{e}p \rightarrow epX$, $\bar{e}p \rightarrow e\pi^+X$, and $ed \rightarrow e\pi^-p(p_s)$ reactions will be used to measure the differential cross section and polarized electron asymmetries in the invariant mass region $W = 1.08 - 1.40 \text{ GeV}$ covering the $\Delta(1232)$ resonance in the entire angular range of $\cos\theta^* = -1$ to $+1$ and $\phi = 0 - 360^\circ$. The measurements will be done in a Q^2 range from 0.25 to 3 GeV^2 . These experiments will allow a separation of four response functions, including the σ_e which requires polarized electrons and out-of-plane hadron detection. Moreover, a complete isospin decomposition will be possible. This will permit a complete partial wave analysis to be performed over the entire Δ resonance, for the first time.

Physics goals of the experiments:

The main goal of these experiments is an accurate determination of the magnetic $M_{1+}^{3/2}(Q^2)$, electric $E_{1+}^{3/2}(Q^2)$, and scalar $S_{1+}^{3/2}(Q^2)$ transition multipoles in the $\Delta(1232)$ region, where the superscript indicates the isospin $\frac{3}{2}$ multipoles relevant to the Δ resonance transition. Knowledge of these fundamental quantities in a large Q^2 range will allow stringent tests of models describing the nucleon structure in the non-perturbative regime of QCD. In particular, it will allow tests of gluonic degrees of freedom that are expected to give rise to the color magnetic hyperfine interaction through contributions at short distance, and provide constraints for QCD calculations on the lattice.

Theoretical developments:

It has been known for long time that in the kinematical range where data exist the magnetic dipole transition dominates, and the ratios $R_{EM} = E_{1+}/M_{1+}$ and $R_{SM} = S_{1+}/M_{1+}$ are small. In fact, the data are consistent with $R_{EM} = 0$ for $0 < Q^2 < 1 \text{ GeV}^2$, while at large Q^2 one expects $R_{EM} \rightarrow +1$. At the time the original proposal was approved only non-relativistic quark model calculations were published, predicting a negative value for $R_{EM} \sim -(1-5)\%$, rising with Q^2 throughout the kinematical region covered by our proposal. Relativized quark models, as well as recent calculations within the light cone formalism^[1,2] that do not include configuration mixing give small negative values for R_{EM} while calculations based on a relativistic quark model predict^[3] a sign change and a significant rise to $R_{EM} \rightarrow +0.1$ within the Q^2 range covered by the proposed experiments (Figure 1). This makes it very important to cover a large range in Q^2 . Clearly, accurate data spanning a large Q^2 range would have a real impact on further developments of quark models. Another approach is the distributed string model by Iachello and co-workers^[4] which makes predictions for the Q^2 dependence of the M_{1+} multipole. Recent attempts to calculate R_{EM} within the quenched approximation of lattice QCD^[5] are presently limited to the photon point. Quark-diquark models^[8] predict large values for R_{SM} at $Q^2 \geq 3 \text{ GeV}^2$, which can easily be tested by these experiments.

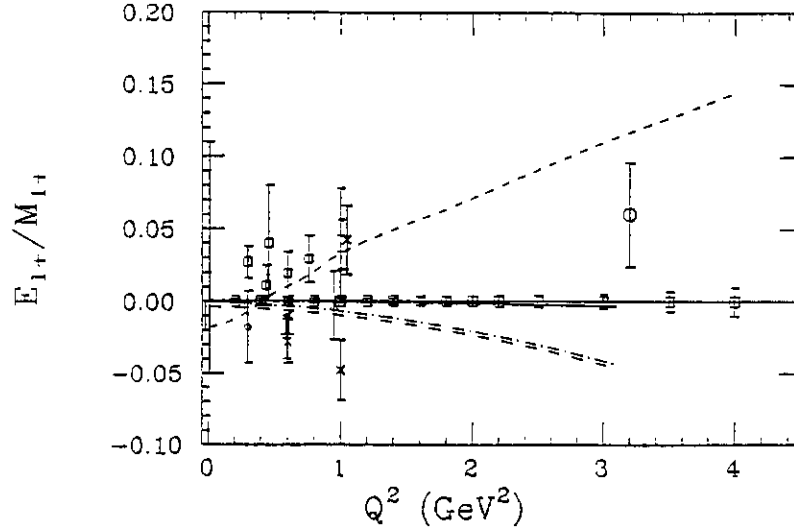


Figure 1: The ratio R_{EM} versus Q^2 . Solid lines represent predictions of nonrelativistic and relativised quark models, the dashed line is the prediction of a relativistic quark model in light cone formalism³

Experimental analysis:

For a model-independent analysis measurements of at least 3 channels with different isospin content are necessary, for example the channels we propose to measure. The isospin composition for all single pion channels are given by:

$$\begin{aligned}
 \langle \pi^+ n | T | \gamma_v p \rangle &= \sqrt{\frac{1}{3}} T_3^v - \sqrt{\frac{2}{3}} (T_1^v - T^s) \\
 \langle \pi^0 p | T | \gamma_v p \rangle &= \sqrt{\frac{2}{3}} T_3^v + \sqrt{\frac{1}{3}} (T_1^v - T^s) \\
 \langle \pi^- p | T | \gamma_v n \rangle &= \sqrt{\frac{1}{3}} T_3^v - \sqrt{\frac{2}{3}} (T_1^v + T^s) \\
 \langle \pi^0 n | T | \gamma_v n \rangle &= \sqrt{\frac{2}{3}} T_3^v + \sqrt{\frac{1}{3}} (T_1^v + T^s)
 \end{aligned}$$

The isoscalar amplitude T^s and the two isovector amplitudes T_1^v and T_3^v can be determined from the 3 channels we have proposed to measure. If only one channel is measured, for example $p(e, e'p)\pi^0$, the relevant $T = \frac{3}{2}$ multipoles cannot be separated from the (non-resonant) $T = \frac{1}{2}$ multipoles and the interpretation of the experiment becomes model-dependent. This is an important advantage a large acceptance spectrometer has, and these experiments make full use of it.

Experiment E-89-037 will determine the quantities $Re(E_{1+}M_{1+}^*)$ and $Re(S_{1+}M_{1+}^*)$ for both isospin $\frac{3}{2}$ and $\frac{1}{2}$. Several other terms related to non-resonant multipoles will be measured as well. Separation of resonant and non-resonant contributions in the multipoles is important as model predictions usually focus on the resonant multipoles. The following techniques will be used to isolate non-resonant contributions in the data analysis:

- (1) measurement and analysis of different isospin channels in the final state.
- (2) analysis of multipole combinations such as $Im(S_{1+}M_{1+}^*)$, etc. These terms are non-zero only in the presence of non-resonant contributions which cause a shift in the

relative phase between the multipoles.

- (3) measurement of the energy dependence of the multipoles.

The analysis is facilitated by the fact that the Δ is a relatively isolated resonance, dominant over the other states in a large range of Q^2 , so that only a limited number of partial waves are needed in the analysis.

Software for the amplitude analysis:

The proposed experiments are part of a larger effort to study the nucleon resonance region using single pion production, as well as other channels, by measuring differential cross sections and polarization observables over the entire kinematical regime. Experimentally, this program minimizes the model-dependence in the determination of resonance transition amplitudes. Because of the possibility of correlations in measured quantities we have embarked on an effort to determine systematic uncertainties with more accuracy. Two software packages, undergoing constant modification, have been developed towards this end:

- (1) The code AO^[6] was written to calculate realistic cross sections for single pion production, using results of partial wave analyses of existing electroproduction data in the nucleon resonance region. Parametrization of resonance amplitudes up to $Q^2 = 3\text{GeV}^2$ have been implemented. In addition, electric Born amplitudes for single pion production have been included. AO has become an essential tool in generating realistic Monte Carlo events.
- (2) We are collaborating in an effort to develop a software package ANA^[7] which allows an analysis of the experimental data with realistic amplitudes. The code contains all known resonances with $J \leq 7/2$ as Breit-Wigner amplitudes, the single pion production tree-level Born terms, and phenomenological terms for additional non-resonant contributions. A multi-channel approach is used to fit the channels $ep \rightarrow ep\pi^0$, $ep \rightarrow ep\eta$, and $ep \rightarrow en\pi^+$, simultaneously. We are planning to expand the code to include the $en(p_s) \rightarrow ep\pi^-(p_s)$ channel on deuterium as well. ANA can also be used to analyse polarization data as they become available. The code has already been used to fit unpolarized electroproduction data in the Delta region^[7]. We are now in the process of significantly reducing the model dependency of the background parametrization especially in the Delta region. This is accomplished by constructing the background partial waves using a polygon approximation of the energy dependence. This procedure becomes possible because of the very accurate data expected from CLAS. The method has been tested with computer generated π^0 and π^+ data that included several resonances and real background amplitudes (Born terms). The fit retrieves the input amplitudes of the Delta with good accuracy, giving us confidence that this method will work with real data as well. Some of the fit results are shown in figure 2. We are presently studying the possibility to include complex background amplitudes.

These software tools will enable us to evaluate uncertainties introduced into the results by systematic uncertainties in the data and by specific assumptions made in the analysis.

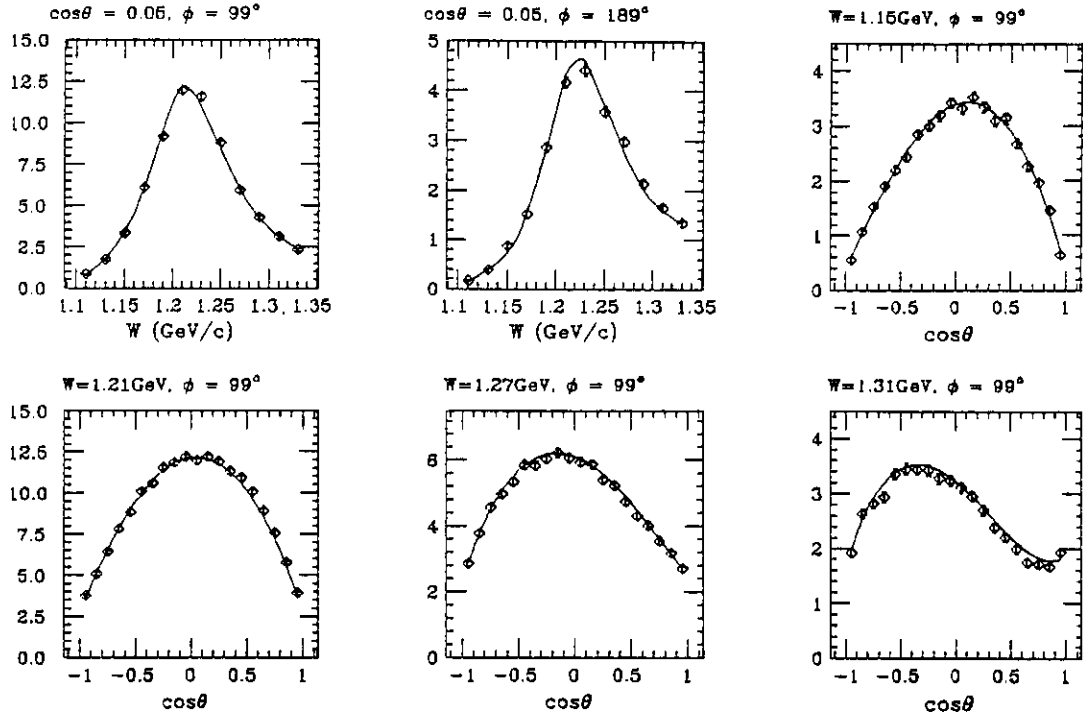


Figure 2: Fit to simulated $ep \rightarrow ep\pi^0$ data using the ANA code^[7]. The Born amplitudes were included in generating the data. In the fit the background amplitudes were reconstructed using a polygon approximation with 8 parameters for each partial wave helicity element. Remaining discrepancies are due to restriction of fitted background partial waves to spin 1/2 only.

Relationship to other experiments:

Although we believe that the experiments will produce high quality data, the systematic uncertainties in the analysis can be further reduced by including the results of experiment E-93-036, which measures the processes $\bar{e}p \rightarrow ep\pi^0$ and $\bar{e}p \rightarrow en\pi^+$ using a polarized NH_3 target and a polarized electron beam. Moreover, experiment E-89-038 and E-89-039 will study transition amplitudes of higher mass resonances, which can be used to better understand their contributions in the Delta mass range.

A recent experiment at ELSA measured $p(e, e'\pi^0)p$, and found a large value for $Re(S_{1+}M_{1+}^*)$ at a $Q^2 \sim 0.1 GeV^2$ in the Δ region. No attempt was made to isolate the resonant contributions. Experiment E-89-03 at Bates has measured the same quantity with improved precision using a polarized beam and a recoil polarimeter. Experiments at facilities such as MAMI or ELSA will likely make measurements in a limited Q^2 range, but due to the limited beam energy, and the lack of large acceptance magnetic spectrometers, we do not see that any significant portion of the proposed program can be addressed at other laboratories.

Significance within the N^* program:

The precise determination of the M_{1+} transition multipole and the small R_{EM} and R_{SM} ratios in the Delta region sets stringent requirements on the performance of the

accelerator as well as the calibration of the CLAS detector. Systematic uncertainties due to detector inefficiencies, or electron beam properties have to be kept to a minimum. It is important that these parameters are controlled at the necessary level. Clearly, this effort will be to the benefit of the entire N^* program which will run in parallel with experiments E-89-037 and E-89-042.

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Update to CEBAF 89-038
Measurement of the $p(e,e'\pi^+)n$, $p(e,e'p)\pi^0$, and
 $d(e,e'\pi^-)pp$ in the 2nd and 3rd Resonance Region

Spokespersons: R.Minehart, V.D. Burkert, M. Gai

Summary of the proposed experiment:

The electromagnetic transition form factors for excitation of N^* resonances will be studied by measuring cross sections in the invariant mass region $1350 < W < 1800$ MeV for the reactions, $ep \rightarrow e\pi^+n$, $ep \rightarrow e\pi^0p$, and $ed \rightarrow e\pi^-X$. The measurement of the scattered electron energy determines both Q^2 and the invariant mass W . The detection of the charged hadron in conjunction with missing mass techniques made possible by the excellent resolution of the CLAS detector will eliminate the effect of background processes to a very high degree. In addition the large acceptance of the detector means that we will obtain an excellent determination of the angles θ^* and ϕ for the decay $W \rightarrow N + \pi$ over their full range. Using incident electron energies of 1.6, 2.4 and 4 GeV in the CLAS detector, these measurements will range over values of Q^2 from 0.25 to 3 (GeV/c)². The kinematical completeness of the measurements on both the proton and the neutron will permit a complete partial wave analysis and isotopic spin decomposition. The experiment will run simultaneously with other N^* experiments, such as 89-037.

To obtain amplitudes for electroproduction on the neutron, cuts will be made in the measurements with the deuteron target to select a kinematical region for which the proton is a spectator. The validity of the spectator model can be tested by selecting a set of data from the reaction $ed \rightarrow e\pi^+X$ for which the neutron is a spectator and comparing the results to the measurements of $ep \rightarrow e\pi^+n$.

Physics motivation:

The motivation for these measurements has not changed in any substantial way since our original proposal. In the region of this experiment, the cross section is dominated by three states, $S_{11}(1535)$, $D_{13}(1520)$, and $F_{15}(1690)$. There are many others that are more weakly excited and that can be extracted if the experiments provide sufficiently accurate measurements of angle and energy dependences. Accurate determination of the Q^2 dependence of the transition amplitudes will test a number of competing models for nucleon structure. The behavior of the amplitudes for production of the controversial $P_{11}(1440)$ resonance (the Roper) will be used to test various hypotheses for its structure.

Relationship to other experiments at CEBAF:

The experiment will yield high quality data that should greatly increase our understanding of the nucleon resonances and their electromagnetic coupling, but still the number of amplitudes is so large that the analysis will not be completely model independent. The polarization measurements of Experiment E93-036 will be helpful because they are sensitive to different observables, in particular to relative phases of amplitudes. This will be important in separating resonant and non-resonant terms. Of course, the polarization experiment can in principle also be used to obtain unpolarized cross-sections, but in practice the constraints imposed on the acceptance by the polarizing magnet and the background from the nitrogen and helium in the target limits the polarized measurements, so that in fact both experiments are necessary.

Relationship to experiments at other laboratories:

No measurements have been made in the intervening period to eliminate the need for our experiment. Proposals for Bates and European facilities such as MAMI and ELSA appear to be limited to very low Q^2 studies in the region of the Δ . None of these laboratories have apparatus or energies that will compete with the CLAS detector at CEBAF. As discussed in the original proposal, existing data in this region are sparse, and the analyses are highly model dependent. The improvement to be expected from measurements in CLAS is enormous.

Related theoretical work:

Since the submission of our N^* proposals, theoretical activity in the field has accelerated, generally with acknowledgement of the motivation provided by our proposed program. The quark model with a harmonic oscillator confining potential and QCD configuration mixing proposed by Koniuk and Isgur¹ has been extended by Close and Li², and by Capstick³ who have incorporated relativistic corrections. Recently Dong, Su and Wu⁴ have explored the use of a linear confining potential with more basic connections to the underlying QCD basis. Weber⁵ has explored the use of light cone calculations to obtain a consistent relativistic treatment of the quark model. Stancu and Stassart⁶ have made calculations for nucleon states using a flux tube model for the interactions between the constituent quarks. These calculations generally stress the need for better electroproduction data to study the Q^2 evolution of the transition amplitudes. Problems associated with the Roper mass and the seeming disappearance in electroproduction has been mentioned by Close and Li as possible evidence for treating the Roper and some higher states such as the $P_{33}(1600)$ as a mixture of gluonic and quark excitations. The different internal structure of hybrid states and quark states with the same quantum numbers can lead to different isotopic relationships and to different Q^2 behavior of the electromagnetic transition form factors. Specific calculations by Li, Burkert and Li⁷ indicate that the hybrid hypothesis can improve the agreement with experimental data on the Roper. They show that the ratio of the amplitudes, $A_{\frac{1}{2}}^p$ and $A_{\frac{1}{2}}^n$ for the Roper should be a good test for distinguishing the hybrid model from the pure quark model. As pointed out by Close and Li, the formation of ratios and linear combinations of amplitudes for measurements from both the proton and the neutron allows one to remove certain common features of confinement and to explore electromagnetic interaction of the quarks to reveal spin-flavor correlations, which in turn may give insight into configuration mixing. Such detailed analysis will require high quality data throughout the resonance region with measurements of enough independent observables to reduce the model dependence of the analysis to a credible minimum.

An algebraic approach to the quark model, incorporating symmetries, is being investigated by Iachello⁸.

Related on-going work:

As discussed in the update for Exp. 89-037 and 89-042, a program to develop data analysis techniques is under way. The computer programs provided by this work will be applied to simulated data to test the effects of systematic errors in this experiment. Ralph Minehart and Volker Burkert are co-chairing the CLAS/EGN working group to build the electromagnetic forward calorimeter to be used in conjunction with the gas Cerenkov counters to identify electrons at the trigger level 1. Volker Burkert is in charge of the calorimeter project at CEBAF. Ralph Minehart is in charge of the design and construction of the analog electronics for the EGN trigger as well as the testing of some 6000 scintillators for the EGN.

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Update for experiment 89-039
**Amplitudes for the $S_{11}(1535)$ and $P_{11}(1710)$ Resonances
from a $p(e, e'p)\eta$ Experiment**

S. Dytman (contact) and K. Giovanetti, spokesmen
18 December, 1995

Studies of N^* resonances are useful as a way to learn about the nonperturbative QCD processes that control baryon wave functions. The purpose of this experiment is to focus on eN reactions with a combination of ηN in the final state. Since the η is an isoscalar particle, only N^* ($T = \frac{1}{2}$) resonances can be excited. In πN experiments, only 2 of the N^* resonances have larger than 6% coupling to the ηN final state. Thus, this reaction is an excellent filter among the many nucleon excited states. This feature has been known for some time and has recently been exploited by photoproduction experiments at Bates¹, Bonn², and Mainz.³

The $S_{11}(1535)$ resonance has a mass slightly larger than the ηN threshold, yet it has unusually strong coupling to ηN . The typical branching ratio for resonance decay to $\eta + \text{nucleon}$ strength is less than 5%. In the nonrelativistic quark model (NRQM), this strength is explained with a delicate balance of $S = \frac{1}{2}$ and $S = \frac{3}{2}$ configuration admixtures.⁴ The $P_{11}(1710)$ state is also unusual, though the data is so sparse that very little is known about it. As with the Roper, it has the same quantum numbers as the nucleon and has also been mentioned as a candidate for a hybrid baryon.

Recent Data

The $S_{11}(1535)$ resonance has received a lot of attention lately because it can be reached via photoproduction at the lower energy labs presently available. However, it is very unlikely any present accelerator will be able to take data of comparable quality to what will be possible at CEBAF, particularly at CLAS. Experiments at Bates (for which Dytman is the spokesman) and Mainz focus on differential cross sections near the threshold for $\gamma p \rightarrow \eta p$; this is the only kinematic range accessible to these accelerators, but it is also quite interesting because previous experiments (mostly published over 20 years ago) failed to see any effects other than the $S_{11}(1535)$ excitation. With much better accuracy than previous experiments, the $S_{11}(1535)$ dominance is still evident in results available at this time. However, the new data has a systematically higher absolute cross section by about 20%. Preliminary indications show that this new level might be hard to reconcile with the $\gamma N \rightarrow \pi N$ data. The Bonn differential cross section data goes to much higher energy ($W \sim 1700$ MeV). The preliminary data of this experiment is in closer agreement with the older data. A first analysis⁵ of the Bonn differential cross section data shows it to be more compatible with the older $\gamma p \rightarrow \eta p$ and pion photoproduction data.

Theory Developments

When this experiment was first proposed in 1989, there was very little modern theory available. There were interesting studies of the N^* wave functions⁴ and photocoupling amplitudes⁶ in the NRQM. A major shortcoming of the NRQM has been its' inability to describe very well known amplitudes for $P_{33}(1232)$ (the delta) and $S_{11}(1535)$. The NRQM photoproduction amplitude is wrong by a factor of 2 for the S_{11} . The S_{11} transition amplitude is also very slowly falling with increasing Q^2 (in sharp contrast to the delta) and the NRQM predictions fall off rapidly for all transitions. Warns, Shröder, Pfeil, and Rollnik⁷ and Li and Close⁸ developed relativized quark models and made calculations for the S_{11}

transition amplitude. With a particular quark potential, Warns et al. were able to generate a result with Q^2 dependence quite similar to that of the present data.

The first relativistic calculation was made by Konen and Weber⁹ using pure s state wave functions. Their light front calculation produces a flat transition amplitude somewhat smaller than the data. A more recent work using s-wave relativistic wave functions¹¹ in a light cone formalism finds important corrections (often greater than 50%) to nucleon form factors and helicity amplitudes for the light resonances such as $\Delta(1232)$ and the Roper. This is because the 3-momentum transfer to the baryon is large for all Q^2 . The transverse response for $S_{11}(1535)$ is surprisingly unaffected while large effects are seen in the longitudinal response. Despite similar assumptions, the results of these two relativistic formulations are not in good agreement with each other. Finally, there has been a quark model calculation of the strong decay amplitudes of N^* to various meson+nucleon states using the 3P_0 model.¹²

These theory developments are quite interesting, but really need modern data for best testing. It is exciting that much more realistic calculations are proving to be technically feasible when the high quality data of CLAS is anticipated. It is still clear that the detection of η 's in the final state is a very useful filter for identification of $T = \frac{1}{2}$ states and that studies of the main states expected to be seen ($S_{11}(1535)$ and $P_{11}(1710)$) continue to be highly motivated.

Analysis software

Analysis of N^* data will require new fitting software of high quality. It seems much of this work will have to be done by the experimentalists. Members of the Pittsburgh group (Vrana and Dytman) and Harry Lee (Argonne) are developing a coupled channels code for optimal fitting of resonance data consistent with important theoretical constraints such as unitarity and inelastic threshold effects. This is complementary to the work being done at CEBAF and will provide an independent analysis of the data.

Experimental Work for CLAS

The spokesmen for this experiment continue to be quite active in the construction of CLAS. Dytman is coleader of the construction group for the region 1 drift chamber; it is being built at the University of Pittsburgh over a 1.5 year period. Giovanetti is in charge of testing and slow controls for the calorimeters.

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Update of **Experiment 89-043**,
Measurements of the Electroproduction of the Λ , $\Lambda^(1520)$ and $f_0(975)$
via the $K^+\pi^-p$ and K^+K^-p Final States*

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and
G. Gilfoyle (Univ. of Richmond)

Abstract

This is an update on the measurement of the angular decay distribution, $W(\theta, \phi, \Phi)$, of electroproduced $f_0(975)$ and $\Lambda^*(1520)$. It summarizes the evolution of the motivations and calculations since the experiment was first approved, considerations for including $f_0(975) \rightarrow \pi^+\pi^-$ decay, and work on the CLAS detector.

Introduction

This proposal, to measure the angular decay distribution, $W(\theta, \phi, \Phi)$, of electroproduced $f_0(975)$ and $\Lambda^*(1520)$, was submitted as part of the original N* program. It was compatible with N* 4 GeV running. The experiment requires the multiparticle CLAS detection capabilities. This capability permits, by measuring the angular decay distribution, $W(\theta, \phi, \Phi)$, a "self analyzing" spin polarization measurement of a decaying final state hadron. Additionally, electroproduction permits use of spin components of the incident virtual photon. Hence electroproduction amplitudes can be determined by measurements of these spin dependencies.

$\Lambda^*(1520)$ Electroproduction

$W(\theta, \phi, \Phi)$ measurements can indicate not only the predominant production diagram but also the spin of an exchanged or intermediate state:

For t - channel exchange processes the $W(\theta, \phi, \Phi)$ dependence for $K^+(494)$, (J=0), exchange will differ from that for $K^{*+}(892)$, (J=1), exchange. E. g. a transverse helicity component of γ_v in the outgoing K^+ Gottfried Jackson frame will produce only transverse $K^{*+}(892)$ amplitude and no $K^+(494)$. (This is similar to pion electroproduction). The $\Lambda^*(1520)$ helicity components can be determined from $W(\theta, \phi, \Phi)$ by use of a $\Lambda^*(1520)$ Gottfried Jackson frame analysis.

For s channel processes, the $\Lambda^*(1520)$ helicity components in the $\Lambda^*(1520)$ helicity frame are just those of the (non strange) s channel N* resonance. These, in turn, are determined by the $(\gamma_v \rightarrow p \rightarrow N^*)$ helicity couplings which therefore determine $W(\theta, \phi, \Phi)$.

$W(\theta, \phi, \Phi)$ calculations for $\Lambda^*(1520) \frac{3}{2}^+$ electroproduction using both unpolarized and polarized incident electrons are being undertaken with Kent State University and in connection with Hall B Experiment 91-024, *Search for "Missing" Resonances*.

$f_0(975)$ Electroproduction

At the time this proposal was presented to the PAC, the $f_0(975)$ $J^{PC} = 0^{++}$ meson was an enigma. Its mass was considerably below that expected for a member of the 3P_0 0^{++} nonet. Suggestions had been made that it was a $q\bar{q}q\bar{q}$ configuration [4] or a K^+K^- molecule [3].

Since this proposal was approved there has been experimental data in CERN pion, proton, and LEAR $p\bar{p}$ reactions indicating that the $f_0(975)$ may indeed be an exotic and not a member of the 3P_0 0^{++} nonet. Several 0^{++} resonances have been identified in the mass region from 1300 - 1600 MeV, the mass range expected for the 3P_0 nonet [1]. These results indicate that not only the $f_0(975)$ but also the $a_0(980)$ may indeed be exotic.

It was suggested, when this experiment was approved by 1989 PAC, that additional observation of the $f_0(975) \rightarrow \pi^+\pi^-$ decay, (branching ratio $\approx 80\%$), be made. Such measurements avoid the contribution of the overlapping $a_0(980)$ which is present in K^+K^- but not in $\pi^+\pi^-$ final states and avoid threshold effects which are present in the K^+K^- final states. We are now doing calculations for these final states. We have had discussions with theorists L. Lesniak,

R.Kaminski, and A.Szczepaniak who emphasized the need for data from both decay channels. From considerations of coupling constants and G parity, t - channel ρ exchange may be a pre-dominant diagram in $f_0(975)$ electroproduction. They are carrying out calculations on this.

The $f_0(975)$ overlaps in mass two strongly electroproduced vector mesons having the same same pseudoscalar final states as the $f_0(975)$, ($\rho(770)$ for $\pi^+\pi^-$ final states, $\phi(1020)$ for K^+K^- final states). Since both the $\rho(770)$ and $\phi(1020)$ are diffractively produced, their helicity amplitudes are approximately known. The $f_0(975)$ electroproduction production amplitudes can be then obtained from the $W(\theta, \phi, \Phi)$ interference terms. Over the last half year, code has been written to calculate $W(\theta, \phi, \Phi)$ for such interfering mesons. The code was used for $f_0(975)$ / $\phi(1020)$ interference with a $f_0(975)$ / $\phi(1020)$ production cross section ratio of 0.1 [2, 5] Using the code, a Monte Carlo simulation of $W(\theta, \phi, \Phi)$ for 3,000 events (corresponding to one Q^2, W bin for 20 days of approved beam time) has been performed and the results fitted with MINUIT. $W(\theta, \phi, \Phi)$ multipoles yielded a precision in the transverse $f_0(975)$ electroproduction amplitude relative to that of the $\phi(1020)$ of $\approx 5\%$. Relative transverse phase angle precision was ≈ 0.2 rad. $W(\theta, \phi, \Phi)$ can also be measured in the mass region near the $\rho(770)$ or $\phi(1020)$ centroid, yielding $W(\theta, \phi, \Phi)$ multipoles characteristic of direct VM electroproduction. This will serve as a check for the above assumed diffractive behavior of the VM electroproduction amplitudes. (For $\rho(770)$ production, there is a Drell $\pi^+\pi^-$ pair production amplitude in addition to VMD).

Work at CLAS

All three spokespersons for the experiment have been involved in the CLAS construction project. Gilfoyle is contributing to the software development for the CLAS drift chambers. He has assumed responsibility for coordinating the activities directed at analyzing and calibrating the drift chamber data. He has developed a tracking package for use with the latest drift chamber prototype and is investigating on-line monitoring algorithms and calibrations schemes. He and three other collaborators have submitted an abstract entitled 'Calibration Strategies for the CLAS Drift Chamber System' to the Vienna '95 Wire Chamber Conference. Funsten and his group at William and Mary have been involved the tests of the electromagnetic calorimeter prototype and software for the EGN calorimeter event reconstruction. Dennis has been involved with software development for CLAS since 1987 and this has been his primary research activity since 1989. Also working with Dennis at FSU on CLAS software, are P. Dragovitsch (a research scientist in the Supercomputing Computations Research Institute), G. Riccardi (a faculty member in Computer Science), X. Zhao (a post doc) and 6 graduates students (5 in computer science and 1 in physics). He has worked on identifying and obtaining the necessary computing resources for CLAS experiments, developed a distributed CLAS Monte Carlo simulation, worked on a distributed event analysis shell and a distributed experiments database.

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Excited Baryon Form-Factors at High Momentum Transfer
N* Collaboration Summary of Experiment 91-002
Spokespersons: P. Stoler (contact), V. Burkert, M. Taiuti

Summary of the experiment.

A central issue of the N* program at CEBAF is which models are valid for describing baryon excitations in different domains of Q^2 . At low Q^2 ($< 1 \text{ GeV}^2/c^2$), the structure is very complex and as yet unsolved. The constituent quark model (*CQM*) with appropriate elaborations has been shown to be the most useful way to characterize these excitations, and provides a motivational basis for much of the N* program. However, the limits of applicability of the *CQM* have never been adequately explored, and it is the main motivation of experiment 91-002 to transcend these limits by measuring resonance amplitudes in regions of Q^2 which have never been accessed. The present experiment is approved to utilize the highest available CEBAF energies, up to 6 GeV, to measure the baryon resonance amplitudes at the highest possible Q^2 , which in this case will allow us to measure up to 6 or $7 \text{ GeV}^2/c^2$ in Q^2 . Due to diminishing amplitudes with increasing Q^2 the measurements will focus on the most prominent resonances. In the first resonance region the $\Delta(1232)$, in the second the $S_{11}(1535)$, and the $D_{13}(1520)$ are the most important, and in the third the $F_{15}(1680)$ is most prominent, at least at low Q^2 .

Physics Issues

What is the physics in this new domain of Q^2 ? At the asymptotically high Q^2 the physics is expected to be greatly simplified since the interactions are describable in terms of *PQCD* and the structure involves only the minimum number of *valence* current quarks. The distribution functions of these *valence* quarks are determined by their non-perturbative interaction with the complicated *QCD* vacuum, and this gives us a handle on treating the non-perturbative *QCD* (*NPQCD*) structure of a hadron.

There is currently a great deal of controversy about what domain of Q^2 corresponds to the transition from *NPQCD* to *PQCD* descriptions. Some^{1,2,3} believe that the *PQCD* hard processes begin to dominate at Q^2 as low as a few GeV^2/c^2 , and point out for example that inclusive cross sections in the resonance region begin to approach the $1/Q^4$ predicted by *PQCD*. Also, the average behavior of structure functions in the resonance region agrees with expectations from duality relating resonance and deep inelastic scattering in the *PQCD* limit. Furthermore, some other exclusive reaction cross sections appear to also approach the predicted *PQCD* scaling. Others^{4,5}, warn that one expects hard processes to dominate only at much higher Q^2 , and that the existing data may also be accounted for by non-*PQCD* treatments. Relativistic versions¹ of the *CQM* make predictions of resonance amplitudes for $Q^2 < 5 \text{ GeV}^2/c^2$. At this time one may conclude that we do not have a generally accepted understanding of exclusive reactions in the multi-GeV regime. However, it may well be that in the interval $3 \text{ GeV}^2/c^2$ to $7 \text{ GeV}^2/c^2$ we are somewhere in the transition region, and it is important to observe the amplitudes for specific resonances to provide crucial data as a basis for characterizing this transition region.

Existing single-arm inclusive electron scattering data have been evaluated⁶, and they show that the three peaks in the resonance region remain very strong relative to background in the entire Q^2 range of this experimental program. However, since cross sections are diminishing as a function of Q^2 , we expect to focus on the four most prominent resonances mentioned above.

Experiment Overview and Some Specific Physics Issues

Angular distribution measurements will be made for single meson decay channels such

as $(e, e'\pi)$ and $(e, e'\eta)$ over a large part of 4π angular interval simultaneously for the entire range of accessible Q^2 and W . In addition to isolating resonances and separating their multipoles, exclusive neutral meson angular distributions will yield a great deal of reduction of the non-resonant background. The neutral π^0 and η channels will be measured by detecting the protons in the kinematically complete $p(e, e'p)\eta, \pi^0$ reactions. Data on the reaction $p(e, e'\pi^+)n$ will also be obtained by direct observation of the charged pion. This channel is particularly sensitive to the isospin 1/2 resonances $D_{13}(1520)$ and $F_{15}(1680)$ and less to competing isospin 3/2 states such as $D_{33}(1700)$, $S_{31}(1620)$. The following are examples of the kind of information we will access.

The $P_{33}(1232)$ multipoles: The transition form factor decreases significantly as a function of Q^2 compared with that of the other states. At low Q^2 in a pure $SU(6)$ constituent mean-field model the $N \rightarrow \Delta$ transition is purely M_{1+} involving a single-quark spin-flip. That this ratio is small at low Q^2 is experimentally verified⁷. At high Q^2 the E_{1+}/M_{1+} ratio is expected to increase steadily with Q^2 , and in the $PQCD$ limit one expects the equality $M_{1+} = E_{1+}$. A crucial test of our understanding of excited baryon structure, and the regions of validity of the extremely different models is to observe the evolution of the E_{1+} and M_{1+} multipoles. When E_{1+}/M_{1+} is as little as ~ 0.1 the decay angular distributions are very different than for a pure M_{1+} transition. Simulations show that we can expect to obtain definitive information on this crucial ratio. Di-quark baryon models⁸ predict a very large ratio S_{1+}/M_{1+} at $Q^2 > 3 \text{ GeV}^2/c^2$. The ϕ and $\cos\theta^*$ dependence of the differential cross section will also be very sensitive to this ratio.

The $S_{11}(1535)$ form factor. This resonance is one of the few large resonances which has a strong coupling to the η decay channel. At lower Q^2 the reaction $p(e, e'p)\eta$ is dominated by S-wave production and exhibits a clear resonant behavior with only small non-resonant contributions. For S-wave production the differential cross section contains only one transverse helicity amplitude A_{0+} . Therefore the resonant transverse multipoles can be directly extracted from this data, with small corrections due to non-resonant contributions. These experimentally attractive features will enable us to study this transition at a very early stage in the program.

Third resonance region. At low Q^2 the cross section in the third resonance is dominated by the $F_{15}(1680)$, which in $SU(3)$ notation is identified as an $N = 2$. Although a strong peak persists at high Q^2 it is not known whether one or more other resonances become relatively more important. The cross section for the bump in the inclusive data appears to trend toward a Q^{-4} , and we want to examine this region in detail.

Ongoing Preparations for the Experiment Preparations for this experiment have been going on extensively. The CLAS spectrometer is central to the entire program. Volker Burkert and Mauro Taiuti are in charge of constructing the forward and large angle calorimeters at CEBAF and Italy respectively, and Paul Stoler is in charge of construction of the Cerenkov detectors at RPI.

One of the major tasks will be to extract the resonance amplitudes from the complex data. The N^* group is currently making progress in developing software⁹ which will extract such amplitudes, using simulated data from the code AO¹⁰. Simulations which we have carried out indicate that even though we will be obtaining exclusive data at considerably higher Q^2 than ever before, the statistical accuracy of the data will be very good even at the maximum Q^2 , enabling us to separate the resonances and obtain accurate amplitudes.

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Update to CEBAF E91-024: Search for “Missing” Resonances in the Electroproduction of ω Mesons

Spokespersons: V. Burkert, H. Funsten, D. M. Manley, B. Mecking

Electroproduction of ω mesons via the $ep \rightarrow ep\pi^+\pi^-X$ reaction will be used to search for a group of missing N^* resonances not observed in πN scattering but predicted by quark models [1,2] to lie in the mass region between 1.72 GeV (ω production threshold) and 2.2 GeV. One explanation for not observing these states in reactions that have a πN formation or decay channel is that their πN couplings are weak [3]. To test the predictions it is imperative that searches be carried out with reactions that exclude the πN channel. The $\gamma p \rightarrow \omega p$ reaction is well suited to search for missing resonances because of the narrow 8.4-MeV ω decay width. It is sensitive to these resonances because the isoscalar ω can couple with the proton *only* to $I = \frac{1}{2}$ resonances, therefore filtering out $I = \frac{3}{2}$ resonances.

Early quark-model predictions by Koniuk [4] show that several missing positive-parity resonances in the $N = 2$ band should have appreciable ωN decays. Koniuk treated the emitted ω as a pointlike particle; more recent calculations [5] by Stancu and Stassart have attempted to treat the emitted ω more realistically as a finite-size particle. Results of the two sets of calculations present important differences for individual resonances. For example, Koniuk predicts the largest ωN couplings for two $N_{\frac{1}{2}}^{5+}$ resonances near 2.0 GeV, whereas Stancu and Stassart predict the largest ωN couplings for two $N_{\frac{1}{2}}^{3+}$ resonances near 1.9–2.0 GeV. Other important theoretical developments include recent studies by Capstick, Roberts, and Isgur of N and Δ resonances in a relativized quark model with chromodynamics [6]. Decay amplitudes were calculated for the ωN channel, among many others, using the relativized wave functions. A unique feature of this work is that decay amplitudes are predicted not only for the lighter baryons in the $N = 0, 1$, and 2 bands but also for the heavier baryons in the $N = 3, 4, 5$, and 6 bands. It will be interesting and important to attempt to identify some of the predicted resonances with large ωN couplings experimentally.

By using CLAS to detect the scattered electron and recoil proton from the $ep \rightarrow epX$ reaction, the missing-mass technique can easily be used to identify ω production events. The only other narrow peaks in the missing-mass spectra are associated with π^0 and η production events, and these are easily resolved. There will also be a background underneath the ω peak from 2π and 3π events. Most of the background can be eliminated by requiring additional detection of the $\pi^+\pi^-$ pair and accepting only events with $0.05 < M_{\pi^+\pi^-}^2 < 0.49 \text{ (GeV)}^2$ and requiring that good events pass a missing-mass cut, $|M_X - M_{\pi^0}| < 0.050 \text{ GeV}$, for the $ep \rightarrow ep\pi^+\pi^-X$ reaction.

We expect to measure the differential cross section for the $\gamma p \rightarrow \omega p$ reaction as a function of both Q^2 and c.m. energy W . Currently, we plan to run this experiment simultaneously with several others that will use a LH₂ target and a 4-GeV beam. Some thought has been given to the advantages and disadvantages of running part or all of the experiment with a 6-GeV beam. The major advantage of using a 6-GeV beam is that it would permit measurements to be extended to

higher Q^2 . It would also permit taking data at higher W , although this is less important because of the complexity associated with the increased number of partial waves at higher W . A disadvantage is that a somewhat poorer missing-mass resolution would result. The ultimate decision to run part or all of the time at 6 GeV will depend on detailed counting-rate estimates, which have not yet been performed; at this time, we are not requesting a change in our original run conditions.

Data for ω production in the resonance region are sparse. For the original proposal, we calculated the differential cross section taking into account t -channel π exchange and vector-meson-dominated diffraction, as well as an s -channel resonance. The calculation showed that backward ω production is dominated by the resonance term. We also calculated the decay angular distribution for ω mesons produced by real photons. The results indicate a strong resonance signal even in the presence of appreciable π exchange and diffraction at nonforward scattering angles. Work is now underway at Kent State University (KSU) and The College of William and Mary (W&M) to modify the ω photoproduction code to permit calculations of the decay angular distribution for ω electroproduction (including polarized electrons). The virtual photon density matrix has been introduced in the code already, following the formalism of Schilling and Wolf [7]. In addition to determining the Q^2 form factor of the γNN^* vertex, electroproduction is advantageous over photoproduction in allowing measurement of four times as many transition amplitudes. Polarized electrons will permit separation of all 26 observable independent spin density matrix elements into contributions from natural- and unnatural-parity exchange in the t channel.

Other ongoing N^* research at KSU by Manley *et al.* is an extension of previous work [8] to determine resonance parameters consistently from partial-wave scattering amplitudes for *all* two-body and quasi-two-body reactions with a πN channel, including πN elastic and inelastic scattering, and single pion photoproduction. Funsten *et al.* at W&M have been working on the CLAS EGN calorimeter in calculations and measurements of the scintillator light readout system. A facility to test the light transmission uniformity of the fiber-optic bundles has been designed and built, and tests for sector 1 are currently underway. Work is also underway to test Lecroy Fastbus ADCs and TDCs against the procurement specifications, and to develop CODA software in preparation for cosmic-ray tests of EGN sector 1.

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Update for proposal 93-006

Two Pion Decay of Electroproduced Light Quark Baryon Resonances

Spokespersons: M. Ripani (contact), V. Burkert

Summary of the proposed measurements and motivation

This experiment will study two pion final states produced in electron scattering off proton and neutron (deuteron) targets. Two pion final states may be produced via three different mechanisms: intermediate $\Delta\pi$ production, intermediate $N\rho$ production, and $p\pi^+\pi^-$ direct production (“*phase space*”). Moreover, all channels can proceed through non-resonant or resonant contributions such as:

$$\gamma_v p \rightarrow N^* \rightarrow \Delta^{++}\pi^- \rightarrow p\pi^+\pi^-$$

Two pion production through nucleon resonance decay is the kind of process we want to study in this experiment.

The CLAS detector in *Hall B* will be used in this experiment to investigate the two pion electroproduction exploring the W and Q^2 dependence of the total cross sections, the differential cross sections for the production of the $\Delta\pi$ and ρN . The large acceptance of the detector will allow measurement of the decay angular distributions of both Δ and ρ , respectively.

A large number of baryon resonances are predicted by many quark models but have not yet been seen ^[1]. Models like the quark-diquark cluster model readily explain the absence of many of these states due to the reduced number of excitation degrees of freedom in such a system. Symmetric quark models with gluon exchange contributions indicate that the $N\pi$ widths of the “missing” states could be small enough that they would have escaped detection in πN phase shift analyses, while their two pion decay widths and their photocouplings may be large enough ^[2] that they could be detected in photo- or electroproduction of multipion final states. Existence or non-existence of these states would have a significant impact on our understanding of the fundamental structure of baryons.

Moreover, there are several states in the non-strange baryon spectrum that are known to have a small coupling to the single pion channel, while being strongly coupled to multipion channels. The low quality of electron beams and the small acceptance of the detectors used in previous experiments made the study of many-particle final states very difficult. The information about the electromagnetic properties of these baryon excited states is therefore poor, especially regarding the Q^2 dependence of the photocouplings. Precise knowledge of the q^2 dependence of their amplitudes will allow tests of symmetry properties within the framework of the single quark transition model.

Simulations and projections performed^[3] for the CLAS have shown that very good background rejection (basically three pion production) can be achieved, as well as good invariant mass reconstruction and high acceptance and detection efficiency. This includes both, channels with three charged hadrons in the final states as well as channels containing a neutron or a π^0 . Figure 1 shows a comparison of the statistics achieved in the only two pion electroproduction experiment at DESY^[4] and the one expected for 93-006 using the CLAS. This will give not only a much higher sensitivity to various partial waves contributing to the differential cross section, but also the spin population of Δ and ρ can be determined precisely, providing additional sensitivity to the different contributions from non-resonant and resonant terms.

The N^* program in *Hall B* and especially the already approved proposals about resonances investigation including the present proposal have generated a new set of calculations and predictions about photocouplings^[5] and hadronic decays of the baryons^[6], that gives a first basis for the future analysis and understanding of the experimental output from CLAS.

Relationship to other experiments

A related proposal has been approved for the real photon beam in *Hall B*^[7], the goal being the measurement of the $p\pi^+\pi^-$ photoproduction off the proton. In our experiment we propose extensive measurements of all the two pion production channels, because the channels with neutral particles have significantly reduced background from Born terms and can therefore give a cleaner resonance signal. Moreover, using electroproduction one can exploit the Q^2 dependence. This is very important since the amplitudes for the higher mass states in the nonrelativistic constituent quark model calculations are expected to increase in relative importance with increasing Q^2 compared to the lower mass states. Another important aspect is that in the ρ meson electroproduction the diffractive and t-channel contributions are reduced with increasing Q^2 .

A new physics interest has arisen about the two pion electromagnetic production after the appearance of the first data from the *Daphne* detector in Mainz^[8]; the total cross sections for all two pion photoproduction channels off the proton have been measured, using bremsstrahlung photons with energies from 450 up to 800 MeV, which means up to the leading edge of the resonances $D_{13}(1520)$. As shown in the figures 2(a,b,c), model calculations are able to explain the strength for the $p\pi^+\pi^-$ channel, but fail dramatically to explain the data for the two channels with neutrals. This fact raises a number of questions regarding resonance couplings and branching ratios and about nonresonant production mechanisms. Interestingly enough, a recent calculation^[9], based on Heavy Baryon Chiral Perturbation Theory, predicts at the two pion threshold more neutrals than expected from phenomenological models. This calculation is strictly valid only very close to the threshold, and an interesting question is whether this could provide clues for understanding the cross section at higher energies. These are questions that experiment 93-006 at CEBAF will help to clarify.

New analysis developments since PAC6 approval

The activity in preparation of the two pion experiment continues: A software package has been developed in the framework of the *CERN-PAW* analysis package, to study many aspects like invariant mass reconstruction, angular correlations and so on. One important aspect of the measurement is the separation of the different mechanisms, $\Delta\pi$, ρN and $p\pi^+\pi^-$ (*phase space*); a first attempt has been made to separate them using the simulated^[3] single channel mass distributions as input to a fit of the overall distribution containing all the three processes together:

$$f(M_p\pi, M_{\pi^+\pi^-}) = p_1 \cdot f_{\Delta^{++}} + p_2 \cdot f_{\rho^0} + (1 - p_1 - p_2) \cdot f_{\text{phsp}}$$

In table I we report the results of the fit: the original number of events is retrieved with good accuracy.

Table I

| channel | originally simulated events | fitted number of events | PAW-Minuit estimated errors |
|----------------------|--------------------------------|----------------------------|--------------------------------|
| $\Delta^{++}\pi^{-}$ | 23070 | 23049 (- 0.09%) | 191 |
| $p\rho^0$ | 62575 | 63362 (+ 1.3%) | 216 |
| $p\pi^{+}\pi^{-}$ | 14311 | 13545 (- 5.4%) | 400 |

Technical contribution to the CLAS project

One of the spokespersons (M. Ripani) and other collaborators in the proposal are working, as staff scientists of the Genova and Frascati sections of the Italian National Institute of Nuclear Physics (INFN), to the design and construction of the Large Angle Calorimeter (LAC) for the CLAS. This calorimeter will allow detection of photons from π^0 and η decay, neutrons and will improve the electron-pion separation; it will increase the solid angle capability of CLAS, and therefore will be essential for experiments requiring large angle electron detection, neutral particles detection and many-particle final state reconstruction.

The design of the calorimeter modules has been completed. They could cover angles in θ from 45° to 75° and a ϕ interval of 120° , or, alternatively, 45° to 105° in θ and 60° in ϕ . Construction and test of the first module is scheduled for the first half of 1995.

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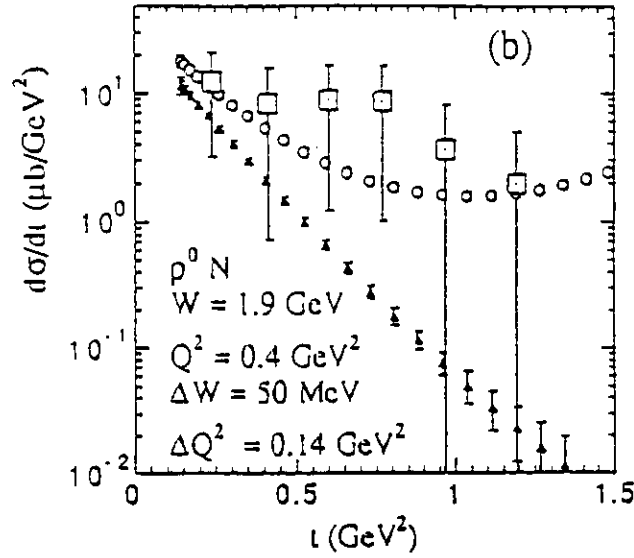


Fig. 1. Differential cross section for $\gamma p \rightarrow p\rho^0$. Existing data (squares with large errors) and projected data for this CEBAF experiment are shown: full triangles without, open circles with the "missing" $F_{15}(1955)$ resonance.

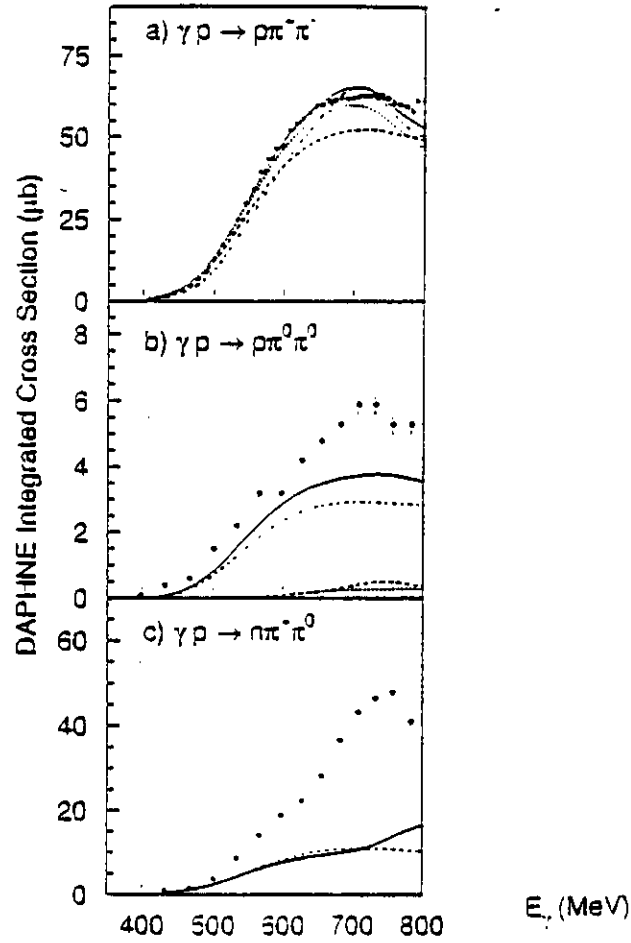


Fig. 2. Total cross sections data for two pion photoproduction off the proton. Dashed curve: calculation from Laget and Murphy using a Born term; dotted curve: the same including the $D_{13}(1520)$ resonance; full curve: the same including the $P_{11}(1440)$ resonance. Dash-dotted curve: calculation from Tejero and Oset. All data and curves from Ref. 8.

UPDATE - CEBAF EXPERIMENT 93-030
Measurement of the Structure Functions for Kaon Electroproduction
K.H. Hicks, M.D. Mestayer, Spokespersons
November 30, 1994

Abstract:

This experiment, a measurement of the kaon electroproduction amplitudes, is intended to probe strong interactions. Since we proposed the experiment, the strong interaction problem has not been solved, theorists are more confident that they can meet the calculational challenges, and we have contributed to the construction of the CLAS detector. The prospects are more exciting today than in 1993.

Review:

CEBAF Experiment 93-030 is a systematic study of the amplitudes governing kaon electroproduction, and will measure the four structure functions, σ_T , σ_L , σ_{TT} and σ_{TL} over the range of Q^2 from 1. to $2.5 \text{ GeV}^2/c^2$ and W from threshold (1.62 GeV) to 2.2 GeV. CEBAF is an ideal place to study the strong production and decay processes, and the strange quark sector is particularly interesting and complementary to non-strange production. Because the Λ is an isoscalar, only $I=1/2$ baryons can contribute to the S-channel; because the s-quark is not a valence constituent of the nucleon it must be produced from the "sea", simplifying quark model calculations and allowing a study of color string breakup; because of its weak decay asymmetry the Λ decay reveals the spin direction of the s-quark. The large acceptance of the CLAS makes possible the separate determination of the individual amplitudes governing the process, effectively isolating different physical processes.

Since approval, the experiment spokespersons have continued their work toward building and commissioning the CLAS, and initiated efforts to build support for strange particle physics CEBAF-wide. In fact, we argue that the scientific motivation and technical feasibility of the experiment are even stronger now than when it was approved.

We address three major areas in this experimental update:

Technical Feasibility:

We concluded our written proposal and oral presentation with a section on "Controls and Calibration" in which we stated "Careful attention to calibrations is necessary." We have concentrated on the major systematic errors (see Table 4, proposal) affecting the CLAS detector and have begun efforts to define the procedures and build the hardware needed to calibrate the detector.

One of us (Hicks) has undertaken the responsibility to calibrate the 17,000 channels of TDC required by the CLAS tracking chambers. The computer-controlled calibration system has been assembled, and has already been used for acceptance testing of the first-article TDC's. One of us (Mestayer) has begun experimental tests to establish the criteria for pulse calibration of the drift chambers which will be designed under his responsibility by CEBAF's fast electronics group. Mestayer

is also a member of the newly-formed 'Calibrations and Commissioning Committee' of the CLAS collaboration, and will lead efforts to calibrate all aspects of tracking, including sieve-slit fabrication, B-field-off cosmic ray runs, and coordination of software efforts to compensate for environmental (pressure, temperature, etc.) changes to drift velocities. He and three other collaboration members have submitted an abstract, "Calibration Strategies for the CLAS Drift Chamber System" to the Vienna95 Wire Chamber Conference. We are encouraged that the collaboration fully supports our efforts to understand and reduce systematic errors in the CLAS setup.

Theoretical Interpretation:

After approval, efforts were begun to sharpen the theoretical interpretation of the anticipated results. Cotanch and Williams have proposed several extensions to previous calculations which they will do for us. We note a recent SLAC-Pub (6688) by Brandenburg, Khoze and Muller in which the authors perform a higher-twist quark model calculation which is directly applicable to $K \Lambda$ production. Discussions with Brodsky, Isgur, Capstick and others indicate a high level of interest.

Of particular note, we organized the "Workshop on Strange Particle Production Experiments at CEBAF", which was held on November 17, 1994. Talks by five theorists (Isgur, Cotanch, Capstick, Onley and Saghai) covered a range of topics from flux-tube breaking to status of models (quark and QHD) to a discussion of polarization effects. Experimenters from the three halls (Baker, Markowitz and Niczyporuk) addressed issues of particle identification, acceptances and systematic errors. We conclude that theorists are as eager for the data as we are, and that calculational support will remain high.

Support Activities for CLAS:

In addition to designing and simulating this experiment, we have contributed to the construction of the CLAS. One of us (Hicks) has assumed responsibility for acceptance-testing and calibrating the 200 96-channel TDC's with which the drift chamber times are measured. This project will culminate in a report documenting the performance of the TDC's as well as a data-base which will serve as a calibration file. One of us (Mestayer) has responsibility for the construction and operation of the CLAS drift chambers. In addition, Mestayer was a member of the Strategic Planning Team on Nuclear and High Energy Physics at CEBAF which issued a report on September 30, 1994 outlining a strategic plan for CEBAF for the next 10 to 15 years.

We have been active members of the collaboration, and are eager to finish construction and begin data-taking.

UPDATE - CEBAF EXPERIMENT 93-012 Electroproduction of Light Quark Mesons

Spokesperson: M. Kossov

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Abstract.

This experiment, a measurement of the amplitudes of electroproduction of radially excited light quark mesons, is intended to measure the $\pi\gamma M^*$ transition form-factors, which provide information on the interaction of light quarks at large distances. During the last year, the idea of such measurements has found a broad theoretical response. Another idea of the experiment, the measurement of the rho-omega mixing, recently became more popular because of the new Quark Loop approach to the problem. Simulation and reconstruction which were necessary for the development of the experiment, stimulated development of the software for the CLAS detector.

Review.

CEBAF Experiment 93-012 is a systematic study of the amplitudes for the electroproduction of light quark mesons. The transition $\pi\gamma M^*$ form-factors will be measured over the range of Q^2 from 1.0 to 3.0 GeV^2/c^2 . All measurements can be done in the framework of the beam time of N^* experiment. Nevertheless in the proposal all acceptances have been calculated for the 6 GeV electron beam too and it was shown that in future experiments at higher energies one can expect a discovery of missing radially excited meson resonances (see Table 1 of the proposal). The CLAS detector at CEBAF is an ideal place to study the electroproduction and decay processes of heavy mesons consisting of the light quarks. High multiplicity of the decays demands large acceptance. The large acceptance of the CLAS detector makes possible not only isolation of the resonance, but angular analysis of the decay process, too.

Since the approval the experiment, we continued our work toward building and commissioning of CLAS, and tried to develop the M^* program at CEBAF. In 1994 the proposal to measure the photoproduction of the vector mesons off nuclei (PR-94-002) was submitted. For the PAC 9 the Letter of Intent to measure K^* meson electroproduction will be presented. Together with the ϕ Meson Electroproduction experiment (93-022) the K^* electroproduction measurements will complete the M^* program at CEBAF.

The scientific motivation and experimental feasibility of the experiment are stronger now than when it was approved.

Experimental Feasibility.

The suppression of the electromagnetic background is crucial for the resonance isolation. A Mini-Torus magnet, which reduces the flow of soft electrons and positrons from the target, was produced in ITEP(Moscow). The simulation software was developed on the basis of GEANT package, including simulation and optimization of the Cerenkov Counters and Shower Calorimeters. The reconstruction programs have revealed possible sources of systematic errors, which could be avoided by proper calibration of the detector. Now the main efforts of the group are concentrated on the calibration of the first components of the CLAS detector.

Theoretical Interpretation.

After approval, additional efforts were begun to develop the theoretical basis for the interpretation of the anticipated results. A few theoretical papers appeared during this short period. At the University of Bonn a group of theorists considered the Electromagnetic Meson Form Factors in the Salpeter Model [1]. In the paper the authors refer to the CEBAF M^* program. V.Belyaev(ITEP/CEBAF) calculated the π - A_1 electromagnetic form factors on the basis of the light-cone QCD sum rules [2]. A group of theorists from Russia(ITEP) and Italy considered Hard Constituent Quarks and Electroweak Properties of Pseudoscalar Mesons [3]. Discussion with Brodsky, Ioffe, Isgur, Smilga and others indicate a high level of interest to the M^* program at CEBAF. The anticipated precise data on $\rho - \omega$ mixing initiated the interest of theorists. In addition to the classic consideration of the problem [4], the new approach to the problem has appeared [5].

Support Activities for CLAS.

In addition to designing and simulating this experiment the ITEP group is contributing to the construction of the CLAS detector. The coils of the Mini-Torus magnet have been made at ITEP (Moscow,Russia), and optimization and design of raster magnets for the polarized target are finished. The software for the development of the simulation, reconstruction, and analysis packages (CLASSIM) was developed. Basic simulation and reconstruction packages for the main parts of the CLAS detector have already been completed and now the main efforts are concentrated on dedicated calibration packages and trigger simulation.

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**Measurement of the Polarization
of the $\phi(1020)$ in Electroproduction**
UPDATE FOR PROPOSAL E-93-022

SPOKESPERSONS: H. Funsten, P. Rubin, E.S. Smith

Review

Experiment 93-022 will measure the polarization of the ϕ meson in the reaction $e^- p \rightarrow e^- p \phi$ at a beam energy of 4 GeV. The polarization of the ϕ meson will be determined from the angular correlations in the decay $\phi \rightarrow K^+ K^-$. The statistical sample will have enough sensitivity to determine the fraction of longitudinal and transverse ϕ 's to 10%. The same sensitivity allows us to measure the fraction of ϕ production due to pseudoscalar exchange mechanisms relative to diffractive scattering. This will be possible because the parity of the exchange determines the sign of the $\cos 2\varphi$ term in the angular decay distribution. An enhancement in this component may indicate a significant strangeness content in the proton.

The high sensitivity of the measurement at 4 GeV – the result of a hundred-fold increase in the number of analyzable ϕ events over previous experiments – is due to the high intensity and duty cycle of the CEBAF accelerator and the large, uniform acceptance of the CLAS detector.

Measurements at Higher Energies

The measurements at 4 GeV significantly constrain the mechanisms of ϕ production by accurately determining the final state polarization of the outgoing vector meson. Additional constraints, and more importantly, model-independent constraints, can be obtained with measurements of vector meson production by (virtual) photons with known polarization. This has been the subject of increased interest and study since the proposal of E-93-022.¹

Data at beam energies from 2.4 to 6 GeV would be used to determine the ratio of longitudinal to transverse cross sections using the standard Rosenbluth technique. We expect to submit a formal extension to the approved program requesting additional running time at 6 GeV. In the sections that follow we outline the physics that can be addressed with these measurements.

Scattering Dependence on the Virtual Photon Polarization

The deep-inelastic scattering (DIS) of an electron off a proton target is traditionally analyzed in the target's infinite momentum frame because in this frame the structure functions

¹“Production of Vector Mesons by Longitudinal Photons,” CEBAF Letter-of-Intent LOI-94-003, and references therein.

can be identified with the quark distributions in the target. However, this simplicity is lost when one considers nuclear target effects and it becomes necessary to analyze DIS in the target rest frame. Which of these two pictures is most useful is determined by the Ioffe time, which is defined as the effective time between the production of the quark pair and its interaction with the nucleus. The Ioffe time is twice as long for transverse photons as it is for longitudinal photons. Thus, the character of the scattering of electrons off a proton is determined in an important way by the ratio, R , of longitudinal to transverse cross sections.

Tests of PQCD-Inspired Models

Exclusive production of vector mesons is believed to be a good testing ground for perturbative QCD (PQCD), because the inclusive production is well described in this framework. Recently, a PQCD-inspired model has been proposed which identifies the pomeron with a two-gluon exchange mechanism.² The model predicts that s-Channel Helicity is conserved (SCHC) and explains a long standing puzzle raised by the EMC collaboration, where the Q^2 dependence of their data is in apparent conflict with the measured decay distributions. This model has been used to predict the exclusive production of ϕ mesons at large momentum transfer. Quark interchanges are suppressed for ϕ production, so the exclusive production of ϕ mesons is a particularly sensitive measure of the two-gluon exchange mechanism.

Systematics

Model predictions and indirect measurements indicate that the longitudinal cross sections are quite large, resulting in values of R above unity. Thus significant constraints can be imposed on the physical processes underlying exclusive vector meson production even with modest measurement accuracy. Model-independent determinations of R with the CLAS detector are limited by systematic uncertainties in the absolute determination of energies and angles. The participants of this proposal are actively studying measurements of this type as part of the CLAS Calibration and Commissioning Working Group.

²J.-M. Laget and R. Mendez-Galain, "Exclusive Photo- and Electroproduction of Vector Mesons at Large Momentum Transfer," CEA-DAPNIA-SPHN-94-24, May, 1994.

Update of Experiment # 93-043

**Measurement of the $\Delta\Delta$ Component of the
Deuteron by Exclusive Quasi-elastic Electron Scattering**

Proposed by:

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Old Dominion University

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College of William and Mary

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This experiment will seek the first direct observation of the two-Delta component of the deuteron's ground state wave function. To isolate the signal of pre-existing Δ 's from final state re-scattering events, we will concentrate on those events which include a Δ moving backwards (relative to \vec{q}) in the lab frame. In particular, to obtain the cleanest signature, we will look for the charged decay products of a backwards Δ^{++} . The 16 days of dedicated running with the CLAS polarity reversed (so electrons bend away from the beam direction) is optimized to allow the detection of these backwards-moving Δ^{++} 's. The experiment has been grouped into the 'e1' running periods because it will share the use of the high-pressure deuterium target and also because there is significant overlap with the lower energy running approved for other experiments in that running period.

The size of the two-Delta component of the deuteron wave function ($P_{\Delta\Delta}$) has been a long-standing experimental question, which has been investigated at many facilities. Experimental progress on this subject is awaiting the availability of a combination of high luminosity, large acceptance, and high momentum transfer, such as will be provided by CLAS. Models of the

deuteron are mature and have long been making predictions of the two-Delta component. Therefore, there has been limited experimental and theoretical activity on this subject since the approval of the experiment in 1993.

An early pre-print¹ by the TAGX collaboration at INS, Tokyo, claimed to have set a new upper limit of 0.14% on $P_{\Delta\Delta}$, based on 13223 events in which $p\pi^+$ pairs were produced on a deuterium target with tagged photons of 566 to 846 MeV. The sensitivity claimed in that preprint appeared to be highly optimistic, and the work has not subsequently been published. A paper² on Δ production from the deuteron was published in 1993 by the TAGX collaboration, but it made no claims of setting a limit on the two-Delta component. Rather, it focused on three different mechanisms for production of the p,n,π^+,π^- final state, which the authors refer to as quasi-free, phase-space and $\Delta\Delta$. The latter includes all production which proceeds through a $\Delta\Delta$ intermediate state, without any requirement that it be pre-existing.

A recent preprint³ outlines a calculation of the $\Delta^{++}\Delta^-$ final state in photo-deuteron reactions. The calculation does not consider any pre-existing two-Delta component, but rather concentrates on re-interactions which excite the second nucleon. In particular, the authors consider diagrams in which the photon-nucleon interaction results in a Δ and a pion, the latter being absorbed by the other nucleon which becomes excited to a Δ . They match the results of the TAGX collaboration, at least at low photon energy. Such additional contributions to the understanding of background reactions may be useful in determining the expected contributions in kinematic regions chosen to emphasize production off of a two-Delta component. Extension of the calculation to electro-production at higher energy will be challenging, however. It is likely that such calculations will provide only a guideline for back-angle extrapolation of the phenomenological re-scattering cross section which will be measured in the present experiment.

The CMU and University of Pittsburgh groups are continuing their activities on the instrumentation of the CLAS spectrometer. They have successfully completed construction and testing of a mechanical prototype of the inner (region I) drift chamber. Procurement of the components for the final chambers is nearing completion, and construction of the chambers will begin in the near future.

1) TAGX collaboration, INS Tokyo preprint INS- Rep.-775 Oct. 1989

2) TAGX collaboration, Z. Phys. A344 (1993)335

3) J.A.G. Tejedor, E. Oset, and H. Toki, IFIC Centro Mixto Universidad de Valencia preprint IFIC/94-54

HAZARD IDENTIFICATION CHECKLIST

CEBAF Proposal No.: _____
(For CEBAF User Liaison Office use only.)

Date: _____

Check all items for which there is an anticipated need.

| | | |
|--|--|--|
| Cryogenics <input type="checkbox"/> beamline magnets <input checked="" type="checkbox"/> analysis magnets <input type="checkbox"/> target type: _____ flow rate: _____ capacity: _____ | Electrical Equipment <input type="checkbox"/> cryo/electrical devices <input type="checkbox"/> capacitor banks <input type="checkbox"/> high voltage <input type="checkbox"/> exposed equipment <i>Standard Hall B</i> | Radioactive/Hazardous Materials List any radioactive or hazardous/toxic materials planned for use: <i>None</i> |
| Pressure Vessels <input type="checkbox"/> inside diameter <input type="checkbox"/> operating pressure <input type="checkbox"/> window material <input type="checkbox"/> window thickness | Flammable Gas or Liquids type: <i>H₂, O₂ Gas</i> flow rate: _____ capacity: <i>less than 1000 cu ft at 1 atm</i> Drift Chambers type: <i>Standard CLAS</i> flow rate: <i>Drift Chambers</i> capacity: _____ | Other Target Materials <input type="checkbox"/> Beryllium (Be) <input type="checkbox"/> Lithium (Li) <input type="checkbox"/> Mercury (Hg) <input type="checkbox"/> Lead (Pb) <i>None</i> <input type="checkbox"/> Tungsten (W) <input type="checkbox"/> Uranium (U) <input type="checkbox"/> Other (list below) _____ _____ |
| Vacuum Vessels <input type="checkbox"/> inside diameter <input type="checkbox"/> operating pressure <input type="checkbox"/> window material <input type="checkbox"/> window thickness <i>CLAS magnet + beam pipe</i> | Radioactive Sources <input type="checkbox"/> permanent installation <input type="checkbox"/> temporary use type: _____ strength: _____ <i>None</i> | Large Mech. Structure/System <input type="checkbox"/> lifting devices <input type="checkbox"/> motion controllers <input type="checkbox"/> scaffolding or <input type="checkbox"/> elevated platforms <i>Standard Hall B</i> |
| Lasers type: _____ wattage: _____ class: _____ Installation: <input checked="" type="checkbox"/> permanent <input type="checkbox"/> temporary Use: <input checked="" type="checkbox"/> <input type="checkbox"/> calibration <input type="checkbox"/> alignment <i>Seed low power laser for PMT Calibration (Standard Hall B equipment)</i> | Hazardous Materials <input type="checkbox"/> cyanide plating materials <input type="checkbox"/> scintillation oil (from) <input type="checkbox"/> PCBs <input type="checkbox"/> methane <input type="checkbox"/> TMAE <input type="checkbox"/> TEA <input type="checkbox"/> photographic developers <input type="checkbox"/> other (list below) _____ _____ | General: Experiment Class: <input checked="" type="checkbox"/> Base Equipment <input type="checkbox"/> Temp. Mod. to Base Equip. <input type="checkbox"/> Permanent Mod. to Base Equipment <input type="checkbox"/> Major New Apparatus Other: _____ _____ |

Standard Hall B equipment for experiments:
 E-89-037, E-89-038, E-89-039, E-89-042, E-89-043,
 E-91-002, E-91-024, E-93-006, E-93-030.

BEAM REQUIREMENTS LIST

CEBAF Proposal No.: _____

Date: _____

(For CEBAF User Liaison Office use only.)

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assessment Document (RSAD) calculations that must be performed for each experiment.)

| Condition # | Beam Energy (MeV) | Beam Current (μA) | Polarization and Other Special Requirements (e.g., time structure) | Target Material (use multiple rows for complex targets — e.g., w/windows) | Target Material Thickness (mg/cm ²) |
|---------------------------|-------------------|-------------------|--|---|---|
| | 1,600 | 0.05 | | high pressure | 50 |
| | 2,400 | 0.100 | | H ₂ , D ₂ | 50 |
| | 4,000 | 0.000 | | ↓ | 50 |
| for Hall B running period | | | | | |
| Setting Experiments: | | | | | |
| | | | 89-037 | | |
| | | | 89-038 | | |
| | | | 89-039 | | |
| | | | 89-042 | | |
| | | | 91-002 | | |
| | | | 91-024 | | |
| | | | 93-006 | | |
| | | | 93-030 | | |
| | | | 89-043 | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

The beam energies, E_{Beam} , available are: $E_{\text{Beam}} = N \times E_{\text{Linac}}$ where $N = 1, 2, 3, 4$, or 5 . For 1995, $E_{\text{Linac}} = 800$ MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the following additional values of E_{Linac} will become available: $E_{\text{Linac}} = 400, 500, 600, 700, 900, 1000, 1100$, and 1200 MeV. The sequence and timing of the available resultant energies, E_{Beam} , will be determined by physics priorities and technical capabilities.

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: _____

For CEBAF User Liaison Office use only.

Date: _____

List below significant resources — both equipment and human — that you are requesting from CEBAF in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments, such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations (either your equip. or new equip. requested from CEBAF)

Standard Hall B equipment

CLAS

New Support Structures: _____

Major Equipment

Magnets

Power Supplies

Targets

Detectors

Electronics

Computer Hardware

Other

Data Acquisition/Reduction

Computing Resources: Standard

New Software: _____

Other

Hall B e1 Run Period

Experiments: E-89-037
E-89-038
E-89-039
E-89-042
E-89-043
E-91-002
E-91-024

E-93-006
E-93-030
E-94-042