CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

This update must be received by close of business on Thursday, December 1, 1994 at:

CEBAF
User Liaison Office, Mail Stop 12 B
12000 Jefferson Avenue
Newport News, VA 23606

Experiment: Hall B E1 running period

Check Applicable Boxes:

☐ Extension ☐ Update ☒ Hall B Update

Contact Person

Name:
Institution:
Address:
Address:
City, State ZIP/Country:
Phone: **FAX:**
E-Mail → Internet:

Given in the individual updates

CEBAF Use Only

Receipt Date: 12/15/94

By: cp

PR 94-144

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

- ______ beamline magnets
- CLAS analysis magnets
- ______ target

type: ______
flow rate: ______
capacity: ______

Electrical Equipment

- ______ cryo/electrical devices
- ______ capacitor banks
- ______ high voltage
- ______ exposed equipment

Standard Hall B

Radioactive/Hazardous Materials

List any radioactive or hazadorous/toxic materials planned for use:

None

Pressure Vessels

- ______ inside diameter
- ______ operating pressure
- ______ window material
- ______ window thickness

Flammable Gas or Liquids

type: H_2, D_2 Gas
flow rate: ______
capacity: less than 1000 cm^3 at 1 atm

Drift Chambers

type: Standard CLAS
flow rate: Drift Chambers
capacity: ______

Other Target Materials

- ___ Beryllium (Be)
- ___ Lithium (Li)
- ___ Mercury (Hg)
- ___ Lead (Pb)
- ___ Tungsten (W)
- ___ Uranium (U)
- ___ Other (list below)

None

Vacuum Vessels

- ______ inside diameter
- ______ operating pressure
- ______ window material
- ______ window thickness

CLAS magnet + beam pipe

Radioactive Sources

- ______ permanent installation
- ______ temporary use

type: ______
strength: ______

None

Large Mech. Structure/System

- ______ lifting devices
- ______ motion controllers
- ______ scaffolding or elevated platforms

Standard Hall B

Lasers

type: ______
wattage: ______
class: ______

Installation: ✓
- ______ permanent
- ______ temporary

Use: ✓
- ______ calibration
- ______ alignment

Several low power lasers for PMT Calibration (Standard Hall B equipment)

Hazardous Materials

- ___ cyanide plating materials
- ___ scintillation oil (from)
- ___ PCBs
- ___ methane
- ___ TMAE
- ___ TEA
- ___ photographic developers
- ___ other (list below)

General:

Experiment Class:

- X Base Equipment
- ______ Temp. Mod. to Base Equip.
- ______ Permanent Mod. to Base Equipment
- ______ 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 Assesment 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	0.100		↓	50
			for Hall B running period		
			Serving 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: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{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_{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.: ____________ Date: ____________
(For CEBAF User Liaison Office use only.)

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:

Data Acquisition/Reduction

Computing Resources: Standard

New Software:

Major Equipment

Magnets

Power Supplies

Targets: High pressure H_2, D_2 Gas targets.

Detectors: CLAS in standard configuration

Electronics

Computer Hardware

Other

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

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
91-002
91-024
93-006
93-030

Overview of e1 Run Period Experiments

S. Dytman

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 86 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 $Q^2 \leq 2$ 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 Quasieleastic 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.

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ANALYSIS SOFTWARE OF THE N^* PROGRAM

V. Burkert, L. Elouadrhiri, Zh. Li

1 Introduction

One of the goals of the N^* program is to extract the photocoupling amplitudes for the known resonances in a large Q^2 range. These observables are directly related to any model of the baryons' structure.

The large amount of data expected to be collected in experiments associated with the N^* program should allow a comprehensive analysis of the entire resonance region simultaneously. Ideally, one would like to analyse all channels $N\pi$, $N\eta$, $N\rho$, $N\omega$, $\Delta\pi$, $N\pi\pi(p.s.)$, etc. together in a consistent coupled channel analysis. However, at the present time the theoretical framework for such an analysis is not available. Also, we expect much more detailed information to be available on single pion or eta production channels than on the multipion processes. We are therefore presently developing the analysis software for the pseudoscalar meson production independently from the vector mesons and and $\Delta\pi$ channels. In the following we will present the analysis method adopted and the first results, we will conclude with a brief discussion of our plan for future development.

2 Single pion and eta production experiments

Experiment 89-037, 89-038, 89-039, 89-042, and 93-009 aim at extracting the photocoupling amplitudes for the know resonances $\Delta(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $D_{13}(1520)$, $S_{31}(1620)$, $S_{11}(1650)$, $F_{15}(1680)$, $F_{37}(1950)$, and many others, at fixed Q^2, over a Q^2 range up to 3 GeV^2 with high precision. Experiment 89-040 will extend this to higher Q^2, with reduced accuracy.

Separation of resonances with different spin/parity requires measurements of complete angular distributions for a number of final state channels so that a partial wave analysis may be performed. The measurements will have complete coverage in the cms pion and eta emission angles. Full coverage in the azimuthal angle allows separation of the $\cos\phi$ and $\cos 2\phi$ dependent response functions in the differential cross section, and provides excellent checks of systematic uncertainties in the measurements.

The separation of resonances of different isopins (N^*, Δ^*) states requires measurement of different isospin channels. In case of single pion production, there are 3 isospin amplitudes, one isoscalar, and two isovector amplitudes, requiring 3 independent measurements to determine the isopin content of the reaction unambiguously. We can choose the following reactions: $ep \to ep\pi^0$, $ep \to en\pi^+$, $en \to ep\pi^-$ (with the last one using a deuteron target). Most of the resonances listed above have dominant branching ratios into these channels.

In the case of eta production only two isospin channels $ep \to ep\eta$ and $en \to en\eta$

exist, the latter one being difficult to measure accurately. Eta production is a filter for isospin 1/2 states. Presently only two states are known to have significant partial widths to $N\eta$, the $S_{11}(1535)$ and $P_{11}(1710)$, which are the subject of experiments 89-039.

Analysis of unpolarized cross section data alone requires assumptions about the energy dependence of the resonant (Breit-Wigner) and nonresonant (Born) amplitudes and smooth varying background. When searching for new states an energy-independent partial wave analysis is more suitable. Such an analysis requires measurement of polarization observables which will give independent information about the size of amplitudes and their energy dependence. Partial wave analyses may then be performed at fixed energies. Such type of analysis has been possible with photoproduction data and it is the goal of the N^* program to do this for the electroproduction data collected at CEBAF.

Experiments using polarized beam and polarized targets will give information about many additional response functions, although typically with reduced statistical accuracy. Measurement of polarization observables will be particularly important for the determination of amplitudes of small resonances such as the $P_{11}(1440)$ and the phase relationship between amplitudes.

3 Single pion and eta production analysis method and first results

The fact that hadronic channels are not only produced by resonance decays but also by nonresonant processes makes it necessary to have a model describing these contributions. ANA[1] is being developed as an analysis package to fit the experimental single pseudoscalar meson data. It will undergo several phases of developments. In a first phase an isobar model type analysis[2] is used. It implements an energy-dependent description of the amplitudes: Breit-Wigner amplitudes to describe resonance shapes, Born terms for nonresonant pion production, and additional phenomenological contributions. The various isospin channels are fitted simultaneously. The $p\eta$ data are also fitted giving greatly improved sensitivity to the $S_{11}(1535)$ and $P_{11}(1710)$ states. Eta threshold effects on the pion channels are taken into account by analytical continuation of the complex S_{11} amplitudes into the unphysical region below η threshold, leading to the known cusp effect.

This program has been tested with the existing data and gives very good fits to the unpolarized cross sections at all Q^2 (an example is shown in the update section of experiment E-89-037). The extracted resonant amplitudes for the prominent resonances such as $\Delta(1232)$ and $S_{11}(1535)$ are in good agreement with previous analyses.

In order to prepare the CLAS N* data analysis ANA is presently used to analyse simulated events using resonances with known amplitudes. For this purpose, an event generator based on the AO[3] code was developed for each process. AO is currently used for the calculation of differential cross sections and all polarization observables, and is a major tool for generating Monte Carlo events with realistic cross sections. AO uses parametrizations of complex resonance amplitudes extracted from previous experiments. It also implements Born amplitudes for single pion production. A good description of photoproduction data is achieved as well as a reasonable reproduction of the limited electroproduction data up to $Q^2 = 3GeV^2$. Other nonresonant amplitudes can be included to test the sensitivity of the observables to various parametrizations of the nonresonant terms.

The simulated data are then processed through the CLAS tracking and reconstruction code SDA. Geometrical acceptances are fully taken into account. ANA is used to analyse the amplitude content of these 'data'. Presently, reconstruction of the four prominent states $P_{33}(1232)$, $S_{11}(1535)$, $D_{13}(1520)$, and $F_{15}(1680)$ has been tested. In the figure some examples of fits to the simulated data are shown. The fit results for the resonance parameters are shown in the table for $Q^2 = 1GeV^2$. The results confirm that variations in the CLAS acceptance do not affect the fitted resonant amplitudes significantly. Also, the data volume is sufficiently large to support a larger parameter space which will be required if more amplitudes (higher resonances, nonresonant terms) are included.

State	Parameters	$A_{l\pm}$	$B_{l\pm}$	$C_{l\pm}$	Mass
P_{33}	Input	-0.660	1.323	0.000	1.232
	Fit	-0.659	1.317	-0.002	1.232
S_{11}	Input	0.671	-	0.000	1.532
	Fit	0.674	-	-0.006	1.532
D_{13}	Input	0.803	0.580	0.0	1.520
	Fit	0.800	0.578	-0.003	1.520
F_{15}	Input	0.411	0.290	0.0	1.688
	Fit	0.415	0.286	-0.002	1.693

4 Conclusions and future plans

This first phase of this project shows promising results. In a second phase we are planning to implement all polarization observables in the fit. Sensitivity of the extracted amplitudes to polarization observables may then be studied in detail. Using generated data from AO, detailed studies of systematic uncertainties in the extracted amplitudes can be made. In a third phase, different analysis methods will be implemented. In particular, we are planning to employ the fixed-t dispersion relations[4]. This technique implements constraints such as unitarity, analyticity, and crossing symmetry, however, questions about convergence of the partial wave expansion at large t require further studies. Also, the dispersion integral extends to high energies, data beyond the resonance region are therefore needed. Development of an analysis program based on the K matrix method[5] has been started by Dytman, Tabakin, and Varna. This project will produce an independent fitting code for the pseudoscalar final states in a unitary coupled-channel format. Many of the above features will be included. Multipion final states will have to be parametrized in a reasonable way and πN scattering data will have to be fitted simultaneously with the electromagnetic data.

References

[1] V. Burkert and L. Elouadrhiri, to be submitted to Phys. Rev. D

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[5] K-matrix method, see for example: R.M. Davidson, N. Mukhopadyay, Phys. Rev. D42, 20 (1990)

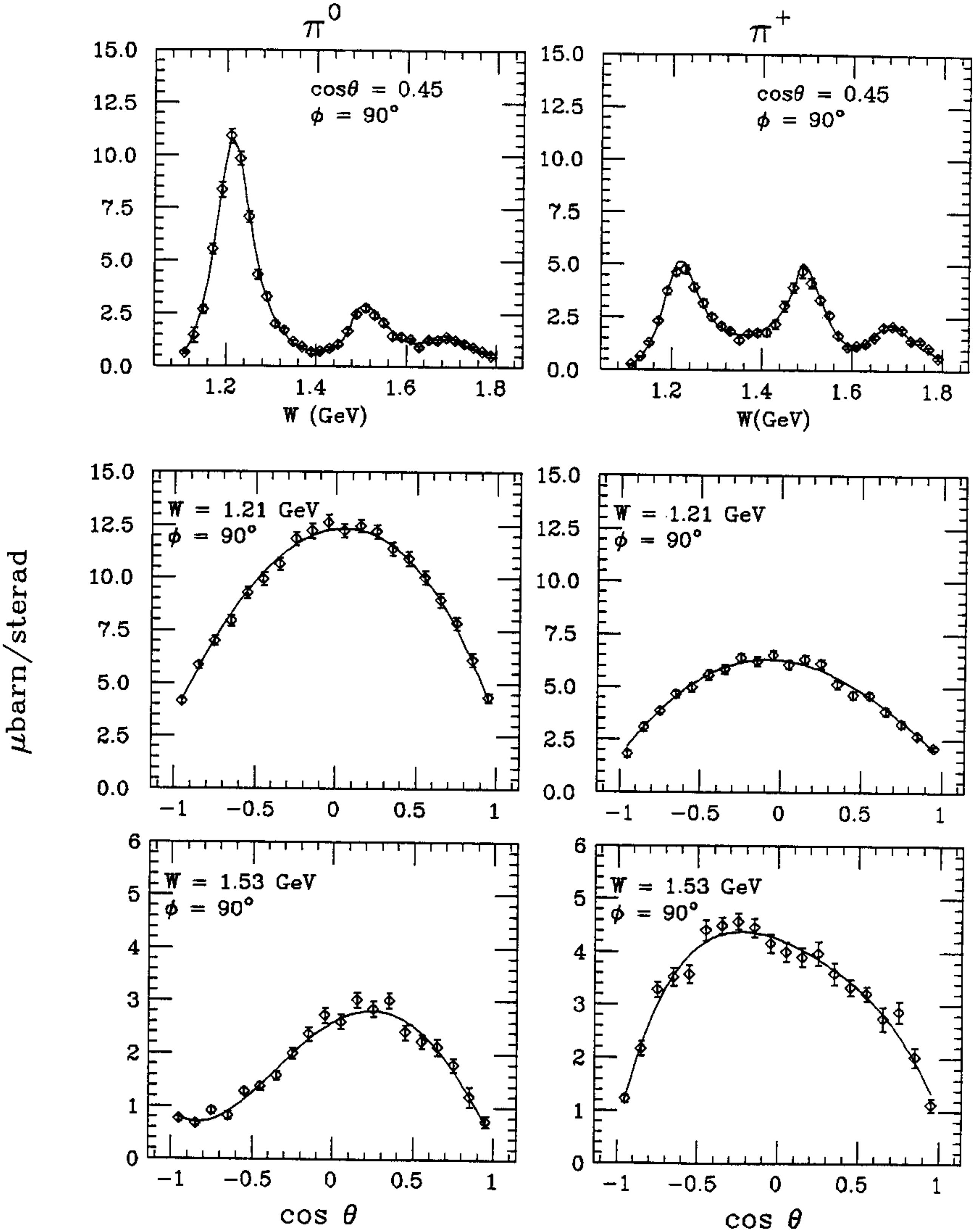

Figure: *Examples of ANA fits to simulated data using AO (E = 2.4 GeV, $Q^2 = 1.GeV^2$, $L = 5 \cdot 10^{33} cm^{-2}s^{-1}$, run time = 250 hrs, bin sizes: $\Delta Q^2 = 0.2GeV^2$, $\Delta\phi = 20^\circ$, $\Delta\cos\theta = 0.1$).*

Theory Issues for N* Experiments

S. Dytman

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 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 realtivistic 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 $Q^2 \sim 3$ 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.

References

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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)π^0 and p(e,e'π^+)n in the Mass Region of the Delta Resonance for $Q^2 \leq 2$ GeV^2

Spokespersons: V.D. Burkert, R. Minehart

Proposed measurements:

Electroproduction of neutral and charged pions via the $\vec{e}p \to epX$, $\vec{e}p \to e\pi^+X$, and $ed \to e\pi^- p(p_s)$ reactions will be used to measure the differential cross section and polarized electron asymmetries in the invariant mass region W = 1.08 - 1.40 GeV covering the $\Delta(1232)$ resonance in the entire angular range of $\cos\theta^* =$ -1. to +1. and $\phi = 0 - 360^o$. 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 $0 < Q^2 < 1.GeV^2$, while at large Q^2 one expects $R_{EM} \to +1$. 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 $R_{EM} \to +0.1$ 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

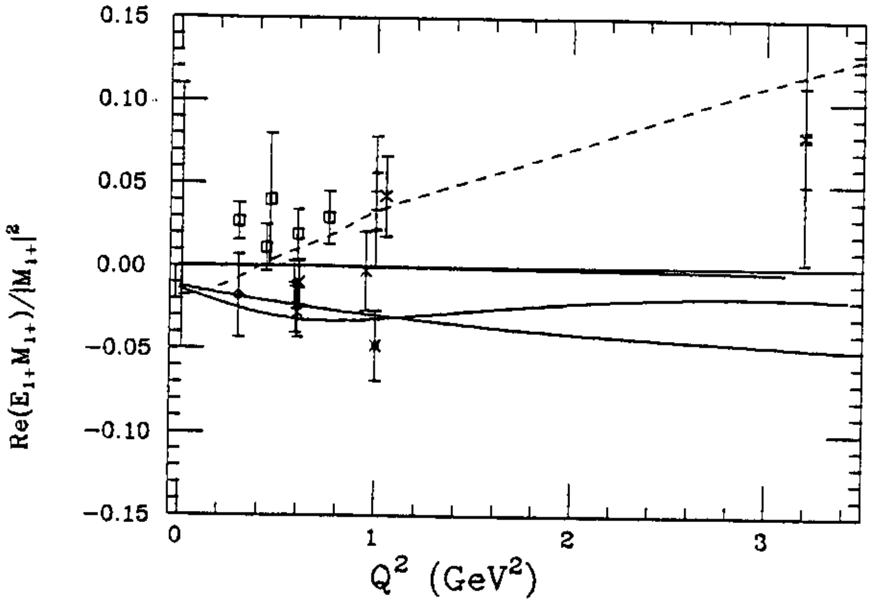

Figure 1: The ratio R_{EM} versus Q^2. Solid lines represent predictions of nonrelativistic and relativised quark models, the dashed line is the prediction of a relativistic quark model in light cone formalism[3]

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 $Q^2 \geq 3\ GeV^2$, which can easily be tested by these experiments.

Analysis procedures:

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:

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

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.

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 $\vec{e}\vec{p} \rightarrow ep\pi^0$ and $\vec{e}\vec{p} \rightarrow en\pi^+$ 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 $Q^2 \sim 0.1GeV^2$ in the Δ region. No attempt was made to isolate the resonant contributions. Experiment E-89-03 at Bates will measure 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 measurement 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 could be addressed at other laboratories.

Development of analysis techniques:

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 polarization observables as well as differential cross sections 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 $Q^2 = 3GeV^2$ 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

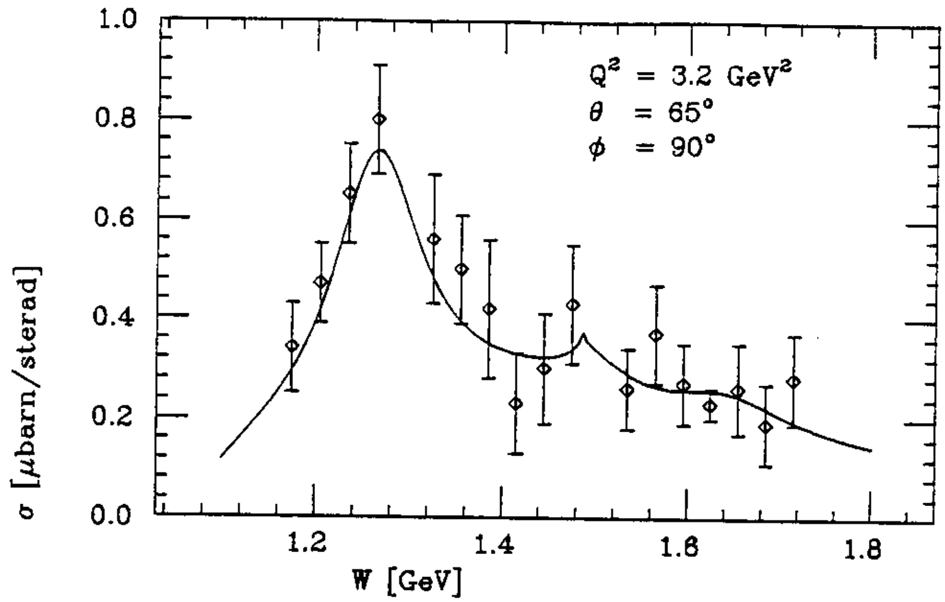

Figure 2: Fit to $ep \to ep\pi^0$ data from DESY, using the ANA code[7]. The spike near W $\sim$ 1.485 GeV is due to the η production threshold (note that η data were fitted simultaneously); 570 $\pi^0 p$ and 47 ηp data were used in the fit.

Carlo events.

(2) We have developed, and are continuing to improve, 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 coupled channel approach is used to fit the channels $ep \to ep\pi^0$, $ep \to ep\eta$, and $ep \to en\pi^+$, simultaneously. We are planning to expand the code to include the $en(p_s) \to ep\pi^-(p_s)$ channel on deuterium as well. Unitarity constraints are included in an 'ad hoc' manner. For example, effects of the η threshold on the pion channels is dealt with by analytical continuation of the resonant η amplitudes below threshold leading to the known 'cusp' effects. ANA can also be used to analyse polarization data as they become available. The code has already been used to fit unpolarized electroproduction data, and gives very good fits (Figure 2). We are planning to implement other analysis techniques such as the fixed-t dispersion relation method and the K-matrix method.

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 performance have to be kept to a minimum. It is important that these parameters are controlled at the necessary level. 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'π^+)n, p(e,e'p)π^0, and d(e,e'π^-)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→eπ^+n, ep→eπ^0p, and ed→ eπ^-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→ eπ^+X for which the neutron is a spectator and comparing the results to the measurements of ep→eπ^+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 Isgur[1] has been extended by Close and Li[2], and by Capstick[3] who have incorporated relativistic corrections. Recently Dong, Su and Wu[4] have explored the use of a linear confining potential with more basic connections to the underlying QCD basis. Weber[5] has explored the use of light cone calculations to obtain a consistent relativistic treatment of the quark model. Stancu and Stassart[6] 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 Li[7] indicate that the hybrid hypothesis can improve the agreement with experimental data on the Roper. They show that the ratio of the amplitudes, $A^p_{\frac{1}{2}}$ and $A^n_{\frac{1}{2}}$ 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 Iachello[8].

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

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 Bates[1], Bonn[2], 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+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 of 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 $\gamma p \to \eta p$; 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 $\gamma N \to \pi N$ 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 analysis[5] of the Bonn differential cross section data shows it to be more compatible with the older $\gamma p \to \eta p$ 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 functions[4] and photocoupling amplitudes[6] 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 Rollnik[7] and Li and Close[8] 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 Weber[9] 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 functions[11] 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. The Pittsburgh group (Vrana, Dytman, Tabakin) is developing a coupled channels code for model independent fitting of resonance data. 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 will be built at the University of Pittsburgh during the next 1.5 years. 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 (γ_v p 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 egnima. It's 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 predominant 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 ($< 1\ GeV^2/c^2$), 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 plan of this experiment and subsequent extensions is to utilize the highest available CEBAF energies to measure the baryon resonance amplitudes at the highest possible Q^2. In the initial phase at beam energy 4 GeV this will allow us to measure up to 4 to 5 GeV^2/c^2 in Q^2. Higher beam energies would be extremely beneficial, and we are currently proposing an extension to electron beam energy of 6 GeV, which would allow us to make measurements up to about $Q^2 = 6$ to 7 GeV^2/c^2. Due to diminishing amplitudes with increasing Q^2 the measurements will focus on the most prominent resonances. In the first resonace 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 versions[1] of the CQM make predictions of resonance amplitudes for $Q^2 < 5\ GeV^2/c^2$. 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 GeV^2/c^2 to $7GeV^2/c^2$ 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 evaluated [6], 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° and η channels will be measured by detecting the protons in the kinematically complete $p(e, e'p)\eta, \pi^\circ$ 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 verified [7]. 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 models[8] predict a very large ratio S_{1+}/M_{1+} at $Q^2 > 3\ GeV^2/c^2$. 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_{o+} 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 software[9] which will extract such amplitudes, using simulated data from the code AO[1]0. 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 $\gamma_v p \rightarrow \omega p$ 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 $N\frac{5}{2}^+$ resonances near 2.0 GeV, whereas Stancu and Stassart predict the largest ωN couplings for two $N\frac{3}{2}^+$ 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° 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 $0.05 < M^2_{\pi^+\pi^-} < 0.49$ (GeV)^2 and requiring that good events pass a missing-mass cut, $|M_X - M_{\pi^\circ}| < 0.050$ GeV, for the $ep \rightarrow ep\pi^+\pi^-X$ reaction.

We expect to measure the differential cross section for the $\gamma_v p \rightarrow \omega p$ 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 LH_2 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:

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

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 ρ N. 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^o. 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:

$$f\left(M_p\pi, M_{\pi^+\pi^-}\right) = p_1 \bullet f_{\Delta^{++}} + p_2 \bullet f_{\rho^o} + \left(1 - p_1 - p_2\right) \bullet f_{phsp}$$

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
$p\rho^o$	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^o 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^o to 75^o and a ϕ interval of 120^o, or, alternatively, 45^o to 105^o in θ and 60^o in ϕ. Construction and test of the first module is scheduled for the first half of 1995.

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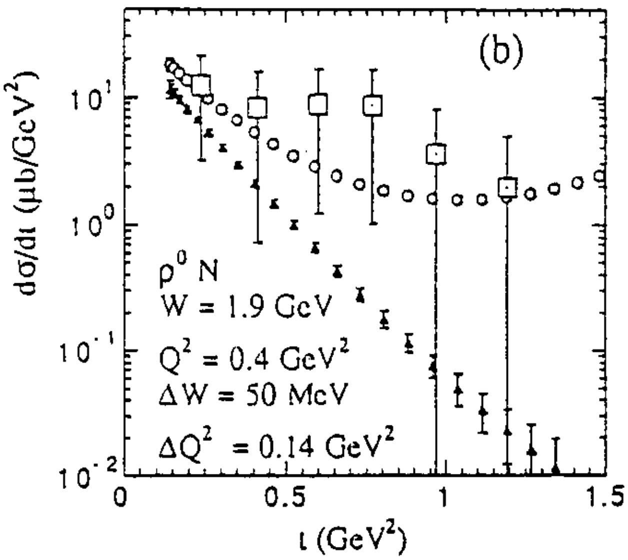

Fig. 1. Differential cross section for $\gamma_v p \rightarrow p\rho^o$. Existing data (squares with large errors) and projected data for this CEBAF experiment are shown; full triangles without, open circles with the "missing" $F_{15}(1955)$ resonance.

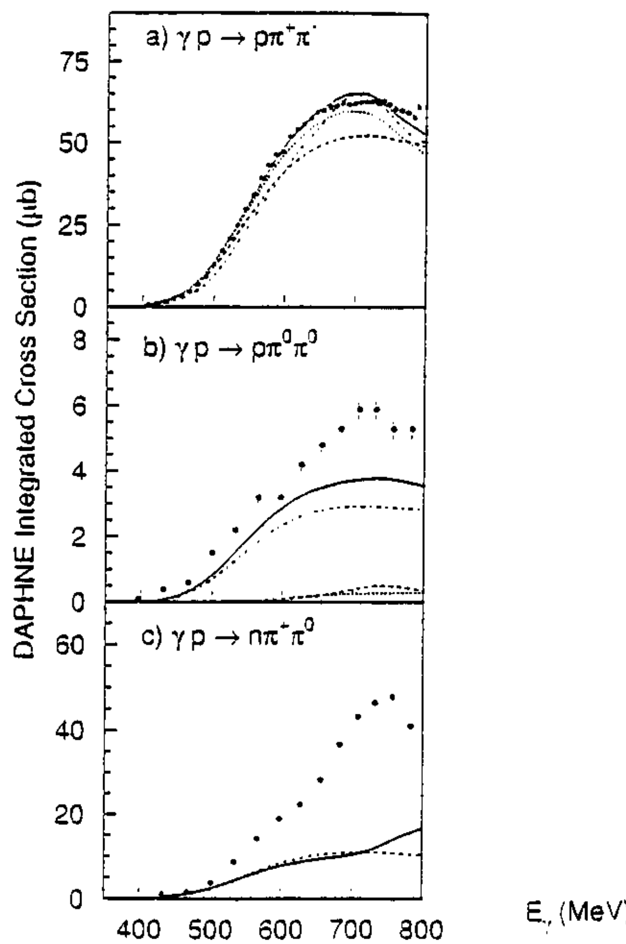

Fig. 2. Total cross sections data for two pion photoproduction off the proton. Dashed curve: calculation from Laget and Murphy using a Born term; dotted curve: the same including the $D_{13}(1520)$ resonance; full curve: the same including the $P_{11}(1440)$ resonance. Dash-dotted curve: calculation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

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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 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

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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 threin.

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 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.

[2] J.-M. Laget and R. Mendez-Galain, "Exclusive Photo- and Electropoduction 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

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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-print[1] 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 paper[2] 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 preprint[3] outlines a calculation of the $\Delta^{++}\Delta^-$ final state in photo-deutron 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