JLab PAC12 Proposal Cover Sheet

This document must be received by close of business on Thursday, June 26, 1997

Jefferson Lab
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(Choose one)

☑ New Proposal Title: Baryon Resonance Electroproduction at High Momentum Transfer

☑ Update Experiment Number: 94-014

☐ Letter-of-Intent Title:

Contact Person

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Experimental Hall: C Days Requested for Approval: 20

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Receipt Date: 6/24/97 PR 97-002

By: gp

BEAM REQUIREMENTS LIST

Lab Proposal No.: ______________________ Date: ______________

Hall: ________ Anticipated Run Date: ______________ PAC Approved Days: __________

Spokesperson: Paul Stoler
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E-mail: stoler @ rpi.edu

Hall Liaison: ______________

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 No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	5	~150		Liq. H 4cm	280	480

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: ______________________ (For CEBAF User Liaison Office use only.) Date: ______________

Check all items for which there is an anticipated need.

Cryogenics ____ beamline magnets ____ analysis magnets ✓ target type: Liq H flow rate: Standard capacity: target	**Electrical Equipment** ____ cryo/electrical devices ____ capacitor banks ____ high voltage ____ exposed equipment	**Radioactive/Hazardous Materials** List any radioactive or hazadorous/ toxic materials planned for use: ____ ____ ____ ____
Pressure Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Flammable Gas or Liquids** type: ____ flow rate: ____ capacity: ____ **Drift Chambers** type: ____ flow rate: ____ capacity: ____	**Other Target Materials** ____ Beryllium (Be) ____ Lithium (Li) ____ Mercury (Hg) ____ Lead (Pb) ____ Tungsten (W) ____ Uranium (U) ____ Other (list below) ____ ____
Vacuum Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Radioactive Sources** ____ permanent installation ____ temporary use type: ____ strength: ____	**Large Mech. Structure/System** ____ lifting devices ____ motion controllers ____ scaffolding or ____ elevated platforms
Lasers type: ____ wattage: ____ class: ____ Installation: ____ permanent ____ temporary Use: ____ calibration ____ alignment	**Hazardous Materials** ____ cyanide plating materials ____ scintillation oil (from) ____ PCBs ____ methane ____ TMAE ____ TEA ____ photographic developers ____ other (list below) ____ ____	**General:** Experiment Class: ____ Base Equipment ____ Temp. Mod. to Base Equip. ____ Permanent Mod. to Base Equipment ____ Major New Apparatus Other: ____ ____

LAB RESOURCES LIST

JLab Proposal No.: ____________________ Date ____________________

(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab 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.

— No new equipment or special resources

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

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets:

Power Supplies:

Targets:

Detectors:

Electronics:

Computer Hardware:

Other:

Other:

Baryon Resonance Electroproduction at High Momentum Transfer

(Extension of TJNAF-CEBAF Experiment 94-014)

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Spokespersons - V. Frolov, J.Price, P.Stoler (contact person)

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ABSTRACT

In Hall C experiment 94-014 the excitation of the $\Delta(1232)$ and the $S_{11}(1535)$ resonances were observed via their decay into the π^0 and η respectively at near 2.8 and 4 GeV^2/c^2. It is proposed to extend these measurements to Q^2 near 6 GeV^2/c^2 utilizing a 5 GeV electron beam. The experiment will measure the kinematically complete reactions $p(e, e'p)\pi^0, \eta$. Since at high Q^2 the protons emerge in a narrow cone around the $\vec{q}$ vector, a large fraction of the in-plane and out-of-plane c.m. decay spectrum can be reconstructed using the HMS and SOS spectrometers. The objective of the experiment is to measure the resonance amplitudes at as high Q^2 as obtainable at TJNAF in order to assess the transition between low Q^2 physics, where *soft* non-perturbative QCD processes characterized by constituent quarks dominate, to the high Q^2, regime where *hard* QCD processes characterized by current quarks, and eventually pQCD becomes increasingly important. Such measurements at these Q^2 have not been previously possible.

Reaction: $p(e, e'p)\pi^0, \eta \quad @ Q^2 \approx 6\, GeV^2$

E_{beam}	I_{max}	target	beam time	proton detector	electron detector
$5 GeV$	$160 \mu A$	4cm L H	20 days	HMS	SOS

1. Introduction

A unique advantage of TJNAF is the ability to measure exclusive coherent reaction amplitudes at increasingly large momentum transfers. This was not possible with earlier facilities since the cross sections for coherent amplitudes fall much more rapidly with Q^2 than incoherent amplitudes which dominate the deep inelastic scattering regime.

Examples of coherent reactions which can be accessed include nucleon and meson elastic form factors and inelastic amplitudes. Experiment 94-014 in Hall C and 91-003 in Hall B are concerned with the measurement of single pion and eta electroproduction in the baryon resonance amplitudes at momentum transfers higher than previously accessible.

Experiment 94-014 was run successfully in November 1996. Electroproduction wasmeasured via the reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$ at $Q^2 = 2.8$ and 4 GeV^2/c^2, $p(e,e'p)\eta$ from the $S_{11}(1535)$ at $Q^2 = 2.4$ and 3.6 GeV^2/c^2, with electron energies 3.2 and 4.0 GeV respectively. The quality of the data appears excellent, encouraging us to propose to push the Q^2 frontier to 6 GeV^2/c^2 by extending Experiment 94-014 utilizing an electron beam energy of 5 GeV.

The physics issues pertaining to this proposal relate to the non-perurbative structure of the hadron, and the controversy about the relevant degrees of freedom and the reaction mechanisms which are appropriate to describe them, as the selected size and substructure of the hadron varies with Q^2. At low Q^2, near the real photon limit where the full complexity of the hadron is assessed, the constituent quark model (CQM) is currently the most useful basis. At the high Q^2 extreme, the smallest size and simplest component of the hadron structure is selected, corresponding to valence current quarks. Furthermore, at large Q^2 hard mechanisms involving perturbative QCD, with all their attendent simplifications, become increasingly important. Currently no one knows at what Q^2 these hard perturbative mechanisms become important. At intermediate Q^2 ($\sim$ few GeV^2/c^2) the accessed structure is probably different enough from that at low Q^2 (~ 0 GeV^2/c^2) to render the constituent quark model inappropriate, yet complex enough so that pQCD techniques are also not appropriate. In particular the reaction may contain, in addition to hard pQCD processes, a significant, or maybe even dominant contribution from soft processes. Many experiments (for example TJNAF 89-012 $D(\gamma,p)n$) appear to obey constituent counting rules, which are characteristic signatures of pQCD, at momentum transfers far lower than expected, whereas color transparency, which is also a characteristic of hard processes, is not observed in the few GeV^2/c^2 range. The physics of the various high Q^2 experiments is totally related. For example, if the hard mechanisms underly the observed constituent counting in deuteron photodisintegrationn at TJNAF energies, then they must also be observed at even lower Q^2 in this experiment. Conversely, if a completely complementary test (see below) for hard mechanisms gives a negative result, then the constituent counting observed in, for example deuteron photodisintegration cannot be due to pQCD. The current TJNAF program of measuring resonance amplitudes over the highest possible Q^2 range is intended to address these issues.

The two resonances on which we focused in experiment 94-014 are the $\Delta(1232)$ and the $S_{11}(1535)$. There are several reasons for focusing on these two excitations.

2. Specific physics Issues for the Proposed Experiment.

$\Delta(1232)$:

Three important issues which we would like to access are the magnitude and the Q^2 dependence of the $\Delta(1232)$ form factor, and the relative strengths of the contributing multipoles E_{1+}, M_{1+}, and S_{1+}.

Exclusive experiments at lower Q^2 suggest that the Q^2 dependence of the $\Delta(1232)$ form factor may be falling at a rate greater than the nucleon elastic and other resonance form factors. Inclusive single arm electron cross sections at higher Q^2 indicate that this trend may be continuing. This contradicts the Bloom-Gilman duality (Bl-71), which states that the resonances should fall off with Q^2 at a rate equal to the underlying non-resonant processes. However, interpretation of inclusive data is very uncertain due to the impossibility of extracting the relative resonant to non resonant contributions.

The exclusive experiment allows us to extract information about the relative contribution of the E_{1+}, M_{1+}, and S_{1+} amplitudes. The relationship between these is more directly sensitive to the reaction mechanism, even more so than constituent scaling or color transparency.

At low Q^2 in a pure $SU(6)$ non-relativistic CQM the $N \to \Delta$ transition is purely M_{1+} in character, involving a single-quark spin-flip with $\Delta L = 0$. An E_{1+} contribution is not permitted, since the Δ and N are both in $L = 0$ states, which cannot be connected by an operator involving $L > 0$. The addition of a residual quark-quark color magnetic interaction adds higher L components to the Δ wave function, and thus introduces a small E_{1+} component, of perhaps a few percent. At $Q^2 = 0$ the experimental data supports the CQM prediction of M_{1+} dominance extremely well. The most recent, and best data (Be-97) from Mainz bears this out, reporting a ratio $E_{1+}/M_{1+} = -.025 \pm .002 \pm .002$. For $Q^2 > 0$ earlier data indicates this ratio remains small up to Q^2 about 1 GeV^2/c^2, as seen in Figure 1. Interestingly, the CQM which predicts M_{1+} dominance so well, fails to reproduce the magitude of the M_{1+} amplitude to within 70 % of its measured value. At high Q^2, according to valence pQCD only helicity conserving amplitudes should contribute, leading to the prediction $E_{1+}/M_{1+} = 1$. There exist some earlier data (Ha-79) of limited statistical accuracy at $Q^2 = 3$ GeV^2/c^2 which have been evaluated by Bu-95 and by Da-97, suggesting that E_{1+}/M_{1+} rather small, but with a large error, as seen in Figure 1. It appears, we are not near the pQCD limit.

The local duality procedure was designed to account for the admixture of soft and hard processes with increasing Q^2. Recently, local duality was applied to the $\Delta(1232)$ form factor (Ba-97), and it was found to account for the form factor in the few GeV^2/c^2 region, but then falls significantly below the experimental values at higher Q^2, which might be evidence that hard processes are playing an increasing role. Their prediction of $E_{1+}/M_{1+} \sim -0.15$ (see Figure 1.) is very different than the CQM prediction and the pQCD value of +1.

Clearly, measurements with increasing Q^2 should be able to distinguish between these very different physical ideas.

$S_{11}(1535)$:

The form factor for the $S_{11}(1535)$ decays much more slowly than those for the proton or

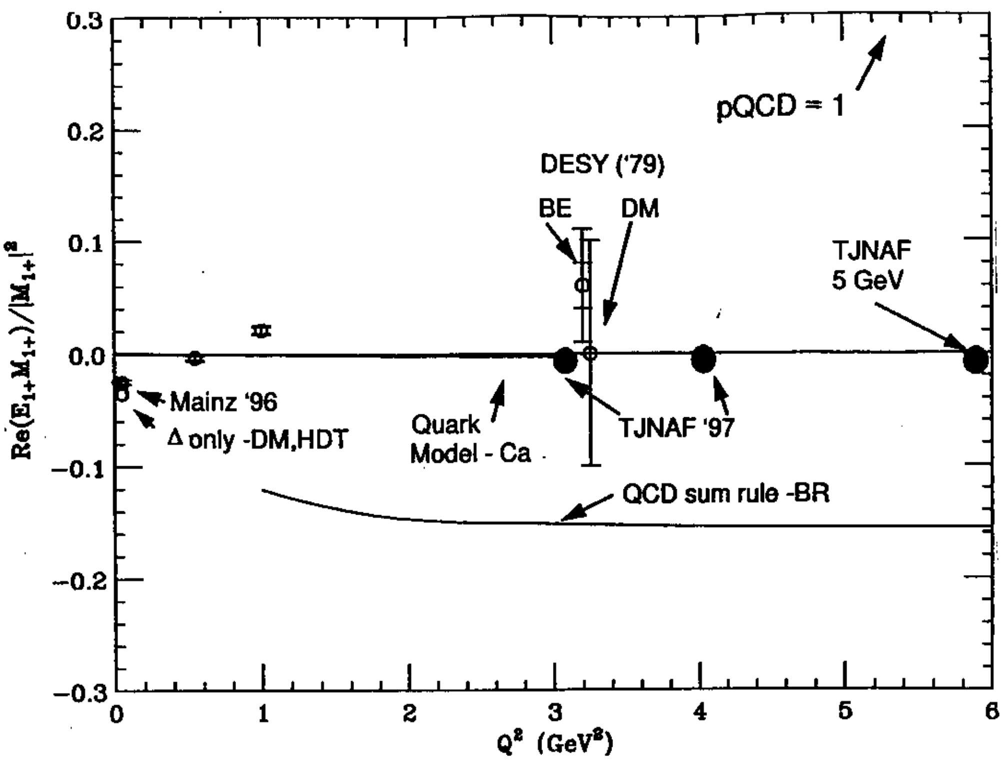

Figure 1. The ratio E_{1+}/M_{1+} (or E_2/M_1) as a function of Q^2. The data at Q^2=0, labelled Mainz, is from Be-97. The data near Q^2=0.5 and 1 GeV^2/c^2 as well as that labelled BE at 3.2 GeV^2/c^2 are due to a recent analysis by Bu-95 of earlier data from DESY (Ha-79). The data point denoted DM at 3.2 GeV^2/c^{2}is due to a recent analysis of the same DESY data by Da-97. The curve labelled QCD sum rule is due to Be-96, and the curve near $E_{1+}/M_{1+} = 0$ is from Ca-92. The predicted pQCD result is off scale at $E_{1+}/M_{1+} = 1$. The two filled circles at Q^2= 2.8 and 4 GeV^2/c^2 correspond to kinematics for Hall C experiment 94-014 for which data were obtained in Nov.-Dec. 1996, and the filled circle at Q^2 = 5.9 GeV^2/c^2 corresponds to the current proposal.

other resonances at lower Q^2. Although the $D_{13}(1520)$ is dominant at Q$^2 = 0$, exclusive data taken up to GeV^2/c^2 suggests a crossover in which the $S_{11}(1535)$ appears to dominate the $D_{13}(1520)$ at Q$^2 \sim$ few GeV^2/c^2 (Ha-79). Single arm inclusive cross section data at higher Q^2 suggests that the peak near the $S_{11}(1535)$ falls at the same rate as the underlying background, and indeed approaches the Q^{-4} dependence predicted by valence pQCD and duality. However, exclusive data does not extend past Q^2= 3 GeV^2/c^2, so all this is conjecture.

A unique feature of the $S_{11}(1535)$ is that it is the only excited state with a large η decay branching ratio ($\sim$ 50%), so that experimentally it is easily isolated. There is also an $S_{11}(1650)$ state. But it has a small η branching ratio, so that there is little interference from any other resonances in η channel. The valence current quark wave function is predicted to be similar to the proton's (Ca-88), and since the spin is 1/2 the reaction is purely helicity conserving, so that this should be a good test case for any evidence of transition from the the dominance of soft to hard processes.

Quark models, primarily based on the Isgur-Karl nonrelativistic quark model, predict values for $A_{1/2}$ and $S_{1/2}$ for this process. Due to the inherently nonrelativistic nature of these models, the applicability of these models at such high values of Q^2 is not known. These

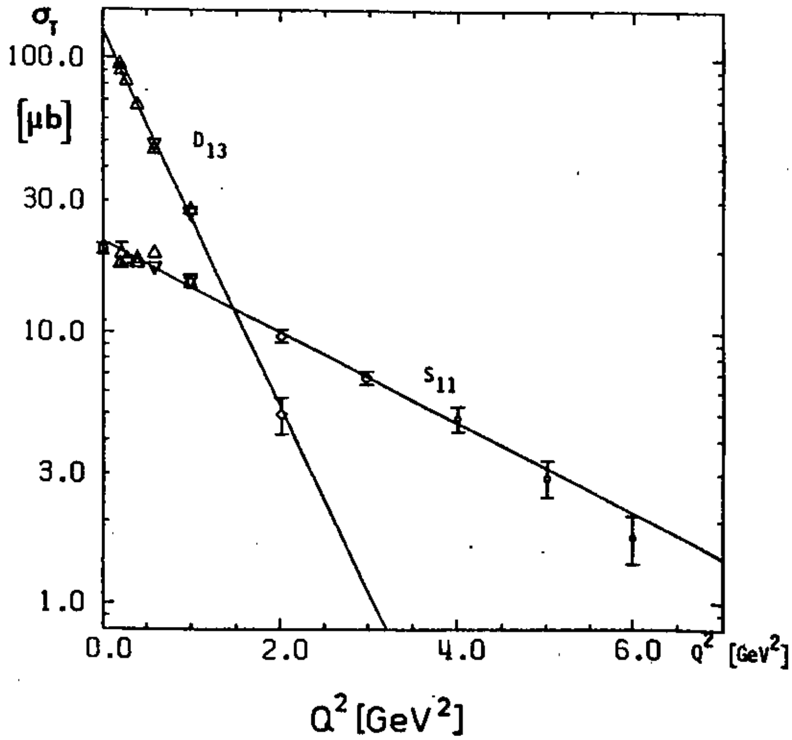

Figure 2. The virtual photon cross section for the excitation of the $D_{13}(1520)$ and $S_{11}(1535)$ from Br-84. The data below $Q^2 = 3$ GeV^2/c^2 are fits to exclusive π^0 and η production, while the data above $Q^2 = 3$ GeV^2/c^2 are simple fits to the bump in the second resonance region of the exclusive data, assuming it is all due to the $S_{11}(1535)$.

models will be strongly tested by higher Q^2data. Certainly, at some value of Q^2, these models break down. Determining this point is one of the goals of this program.

The study of the $S_{11}(1535)$ has historically been done by measuring the cross section for the process $p(e,e'p)\eta$, and assuming that the $|\eta N\rangle$ state must come from the decay of the $S_{11}(1535)$. Recent results from Mainz indicate the possibility of a measurable contribution from the $D_{13}(1520)$, and the latest Particle Data Booklet reports a branching ratio of approximately 10% from the $S_{11}(1650)$. These recent results underscore the necessity of having a precise data set in order to extract the relevant amplitudes. In particular, at high Q^2, since, as mentioned above, the $D_{13}(1520)$ form factor may be falling faster than the $S_{11}(1535)$. As can be seen in Figure 2 at $Q^2 = 3\,(\mathrm{GeV}/c)^2$, the $S_{11}(1535)$ appears to dominate the cross section. Above this point, the data is based on inclusive results, and is assumed to continue to be dominated by the $S_{11}(1535)$. Exclusive data is necessary to confirm this assumption. Jefferson Lab experiment 94-014, currently in analysis, measured η production at Q^2 values of 2.4 and 3.6 $(\mathrm{GeV}/c)^2$. A measurement at 6 GeV^2/c^2 would help clarify the dominance of the $S_{11}(1535)$ in this Q^2 regime.

Unpolarized single meson electroproduction, including η, on the nucleon can be expressed in terms of six complex parity–conserving helicity amplitudes, H_i, which are functions of Q^2, W, and θ^*_η, which in turn can be expanded in terms of Legendre polynomials, as shown in the appendix. The expansion coefficients $A_{l\pm}$ and $B_{l\pm}$ are the transverse partial wave helicity

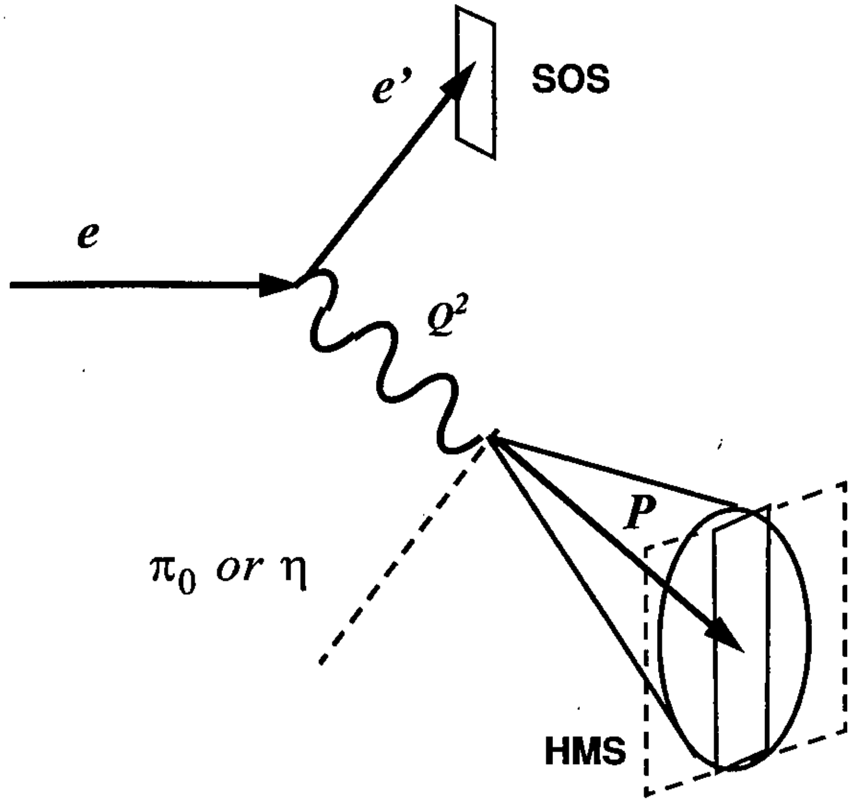

Figure 3. The kinematics of the experiment E94-014 for the reactions $p(e,e'p)\pi^0,\eta$.

elements for $\lambda_{\gamma N} = \frac{1}{2}$ and $\frac{3}{2}$, respectively, and $C_{l\pm}$ are the longitudinal partial wave helicity elements. The differential cross section is directly related to these helicity amplitudes, and thus by measuring the angular distribution for the process $p(e,e'p)\eta$, we can determine the response functions, and therefore the helicity transition amplitudes $A_{1/2}$ and $S_{1/2}$.

3. Analysis of Experiment 94-014

The reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$ at $Q^2 = 2.8$ and 4 GeV^2/c^2, $p(e,e'p)\eta^0$ from the $S_{11}(1535)$ at $Q^2 = 2.4$ and 3.6 GeV^2/c^2, with electron energies 3.2 and 4.0 GeV respectively. The experiment utilized about 200 hrs of beam at a current of nearly 100 μA, producing about 50,000 events each for the Δ and S_{11} at each Q^2 setting. For each beam energy the electrons were detected by the SOS spectrometer, which was fixed in angle and momentum to cover the entire W range from elastic through about 1600 MeV. Protons were detected by the HMS spectrometer. At high momentum transfer the protons emerge in a rather narrow cone around $\vec{q}$ corresponding to 4π in the c.m., as shown in Figure 3.

At 4 GeV about 5 angular and 5 momentum settings of the HMS were sufficient to cover a large part of 4π with 50% overlap between adjacent settings. Since the experiment was kinematically complete, the identification of π^0's and η's was accomplished by missing mass reconstruction on an event by event basis, as were the kinematic variables Q^2, W, and the resonance c.m. decay angles θ_{cm}. This is shown in Figure 4 for one run corresponding to about 1.5% of the total data.

The reconstructed c.m. decay angles are typically about $\delta\phi \sim 3°$ and $\delta(cos\theta) \sim .04$. For

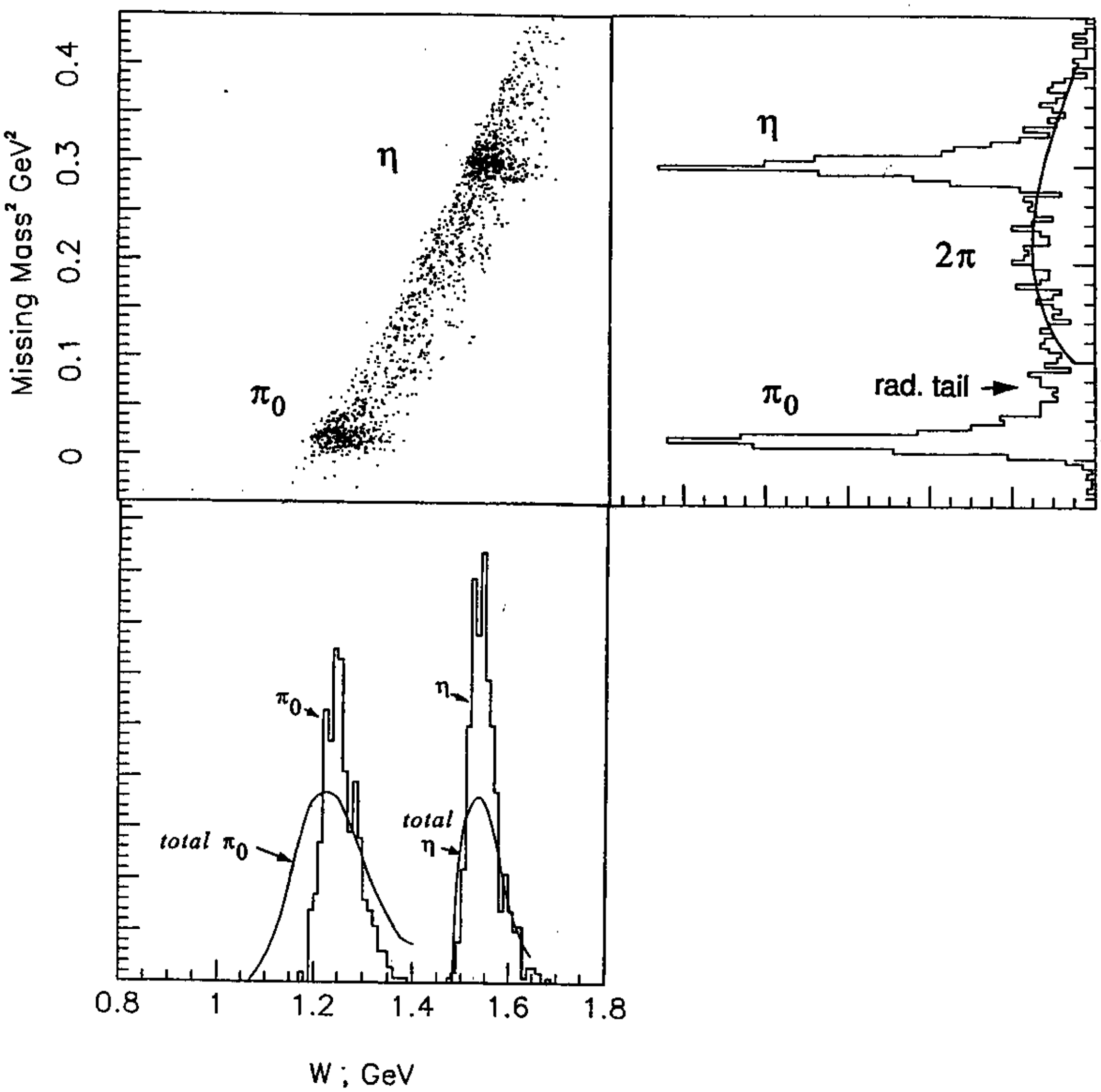

Figure 4. Missing mass squared m^2 vs. W for the reaction $p(e,e'p)$ obtained in experiment 94-014. This corresponds to one kinematic setting in θ_0^{HMS} and P_0^{HMS}. The π^0 and η reconstructions are clearly visible in the projection on the m^2 axis on the right, as is the multipion continuum. The projection on W with a cut on the missing masses of the π^0 and η shows the clean separation of the $\Delta(1232)$ and the $S_{11}(1535)$ by means of π^0 and η production respectively. The kinematic acceptance of this run relative to the widths of the two resonances is illustrated by the solid curves, which are arbitrarily normalized. The data shown consists of about 1.5% of the total for all runs and kinematic settings.

the Δ the 2 pion background is totally eliminated, whereas for the S_{11} only a small multipion background remains. An example of the c.m. angular distribution is shown in Figure 5. With the total array of data we expect to extract E_{1+}/M_{1+} to an accuracy of a few percent.

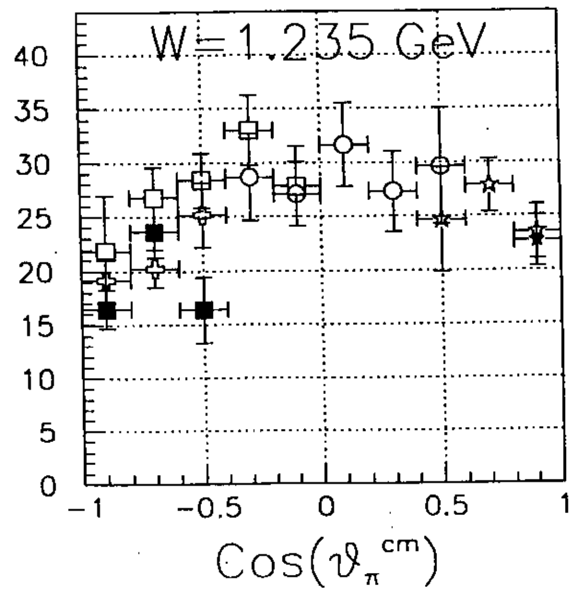

Figure 5. Preliminary center of mass angular distribution for π^0 production at the delta resonance, at W=1.235 GeV and $\phi \sim 0°$ at Q^2= 2.8 GeV^2/c^2, obtained in experiment 94-014. This represents a few percent of the available data at this Q^2. The different symbols correspond to data taken at different HMS kinematic settings. Although the overlap between points from different kinematic settings is reasonable, radiative corrections have not yet been carried out, and improvements in HMS and SOS acceptance and optics corections are in progress.

4. Proposed Experiment

The excellent quality of the data encourages us to propose to push the Q^2 frontier to Q^2 = 6 GeV^2/c^2, utilizing an electron beam energy of 5 GeV. The experiment, as in 94-014 will measure the reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$, and $p(e,e'p)\eta$ from the $S_{11}(1535)$ at Q^2 $\sim$ 6 GeV^2/c^2.

As in 94-014 the scattered electrons will be detected by SOS in coincidence with recoil protons detected by HMS. The SOS central momentum and angle will be fixed throughout the experiment, while the HMS momentum and angle will be varied to cover the resonance decay cone and outgoing proton momentum range. The proposed kinematic settings are listed in Table 1.

The Hall C nominal point to point spectrometer optics tunes will be used for both SOS and HMS. The Hall C data acquisition system and standard trigger setup are adequate for this experiment's needs.

The increase in Q^2 from 4 to 6 GeV^2/c^2 results in a narrower decay cone of the resonance, which makes the total number of settings smaller, and yields greater acceptance at larger out-of-plane center of mass angles. Acceptances as a function of $cos(\theta_{cm})$ for different out-of-plane center of mass angles ϕ_{cm} and different center of mass energies W are shown in Figures 6 and 7 for the $\Delta(1232)$ and $S_{11}(1535)$ respectively.

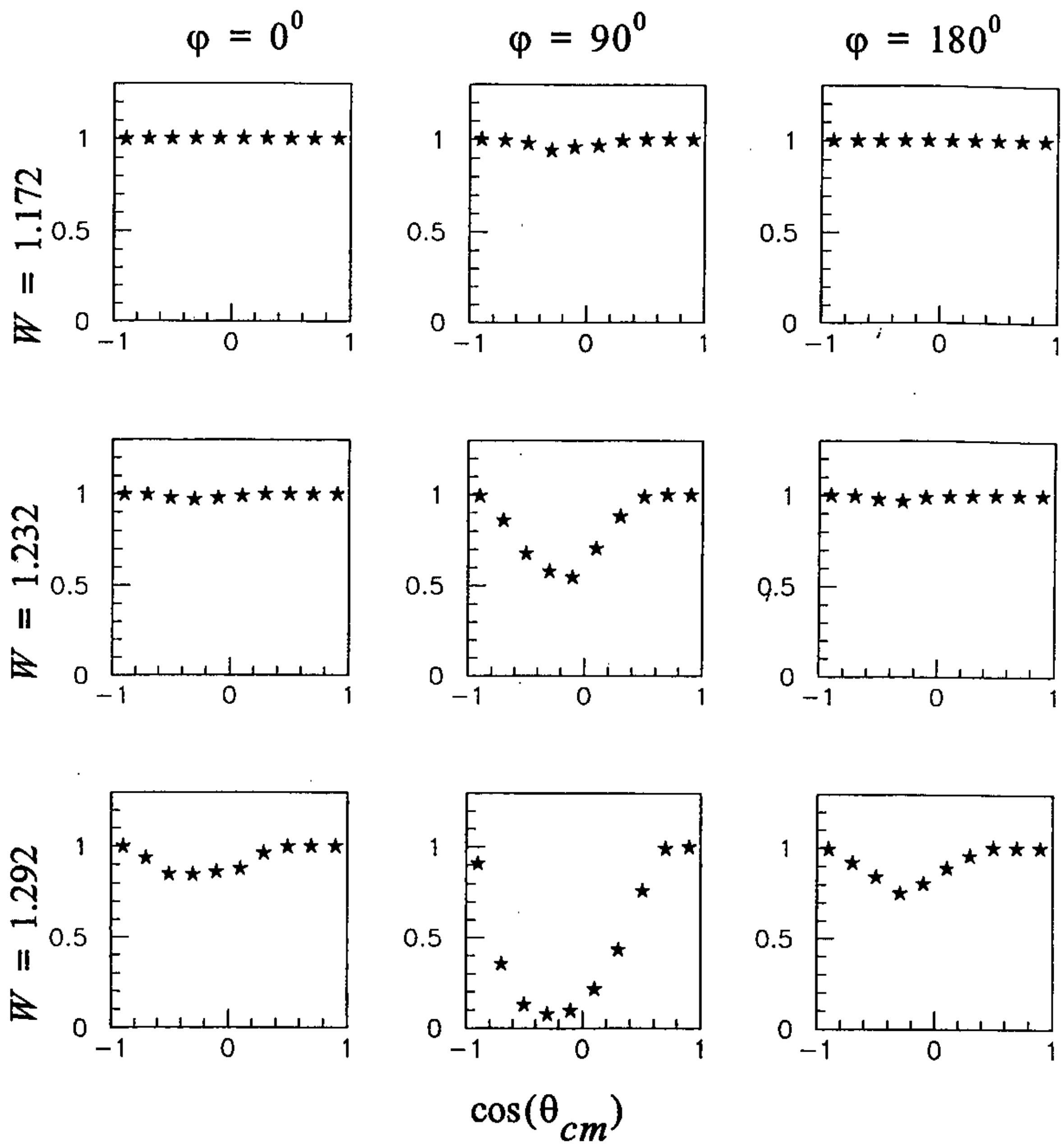

Figure 6. The calculated acceptance function for the reaction $p(e,e'p)\pi^0$ at three values of out of plane angle $\phi = 0°, 90°$, and $180°$ at three values of W near the $\Delta(1232)$, $W = 1.172, 1.232$ and 1.292 GeV.

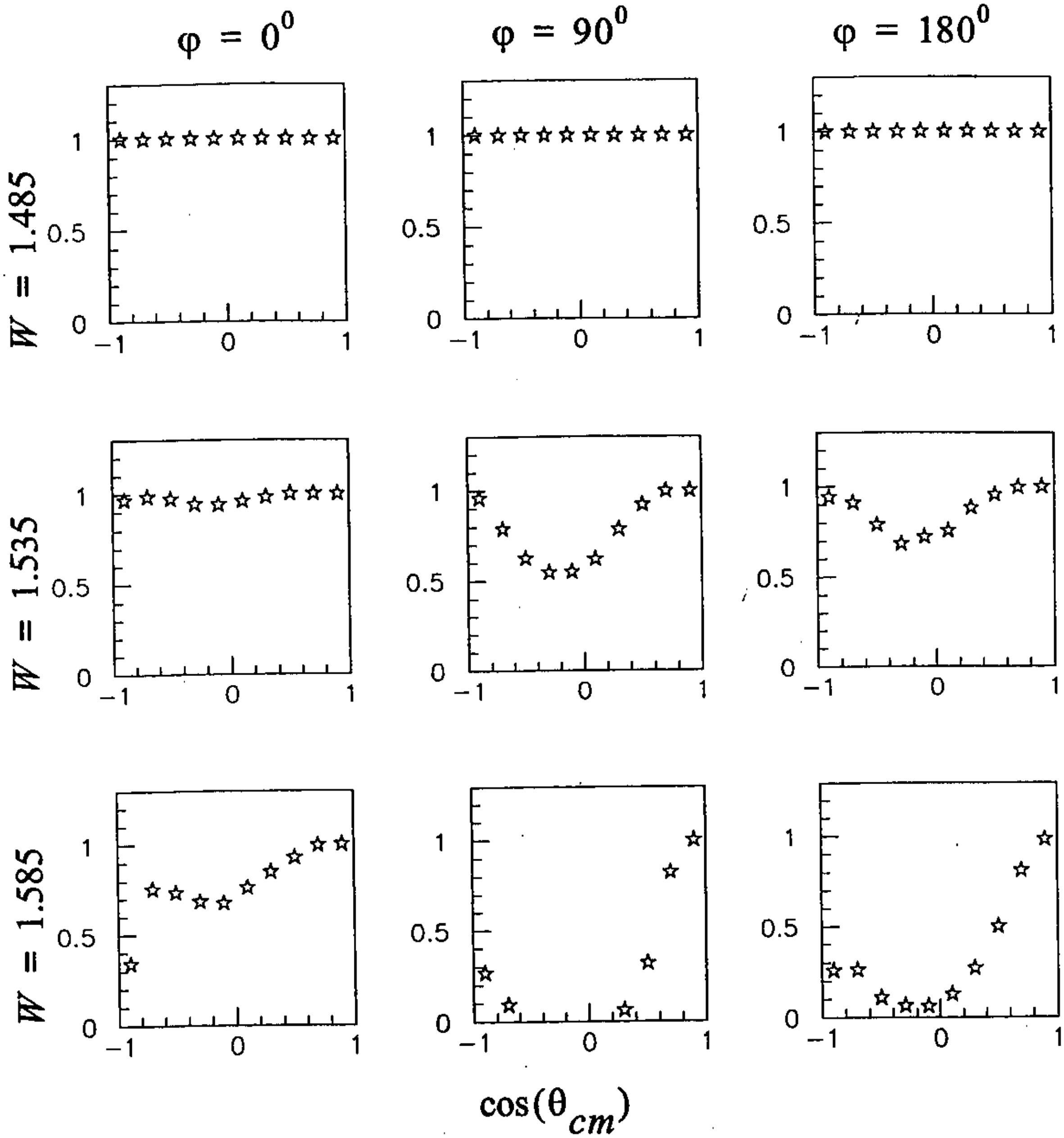

Figure 7. The calculated acceptance function for the reaction $p(e,e'p)\eta$ at three values of out of plane angle $\phi = 0°, 90°$, and $180°$ at three values of W near the $S_{11}(1535)$, $W = 1.485, 1.535$ and 1.585 GeV.

The price one has to pay for increasing the Q^2 is the degradation of the center of mass angular and energy resolutions and missing mass resolution, all by about $\sim$ 20-30 %, which makes it somewhat more difficult to apply missing mass cut to separate the radiative elastic process from the pion production in case of the $\Delta(1232)$ and to suppress the multipion background under the eta peak in case of the $S_{11}(1535)$. Therefore the careful study of the possible background processes will be done during the analysis of the data.

Using a current of 180 μA incident on the Hall C 4 cm liquid hydrogen target, we expect to collect about 50,000 events for each resonance simultaneousely in 20 days of running.

The expected ratio of true to accidental rates is on the order of a few percent within the coincidence peak for the settings at the lowest angle and momentum, and is much smaller for the rest of the settings.

For the entire experiment the SOS momentum and angle will be fixed at $P_0 = 1.5$ GeV/c, $\theta_0 = 53°$.

Table 1 shows the proposed HMS angular and momentum settings.

θ_0^{HMS}	P_0^{HMS}				
12°	2.2	2.5	3.0	3.5	4.0
15°	2.2	2.5	3.0	3.5	4.0
18°	2.3	2.7	3.1	3.6	4.1
21°	2.4	2.8	3.2	3.6	

Table 1. HMS central momemtum and central angle settings in GeV/c and degrees reprectively.

An example of simulated data for π^0 production in the region of the Δ, is illustrated in Figure 8. The simulated data shown represents about 15% of the total expected π^0 over the Δ region. Data off the resonance peak will be used to help pin down the non resonant background. The accuracy to which we would be able to extract E_{1+}/M_{1+} depends on this non-resonant contribution. The three curves are what one would expect for $E_{1+}/M_{1+} = 0$, 0.1 and 0.2. A model linear background was assumed as shown in the figure. The statistical accuracy of the fit shown for $E_{1+}/M_{1+} = 0.1$ is about $\pm$ .004. For the $S_{11}(1535)$, statistics may be comparable or greater, and we would look for deviations from a constant angular distributon, which is characteristic of an s wave decay.

W= 1.232 GeV

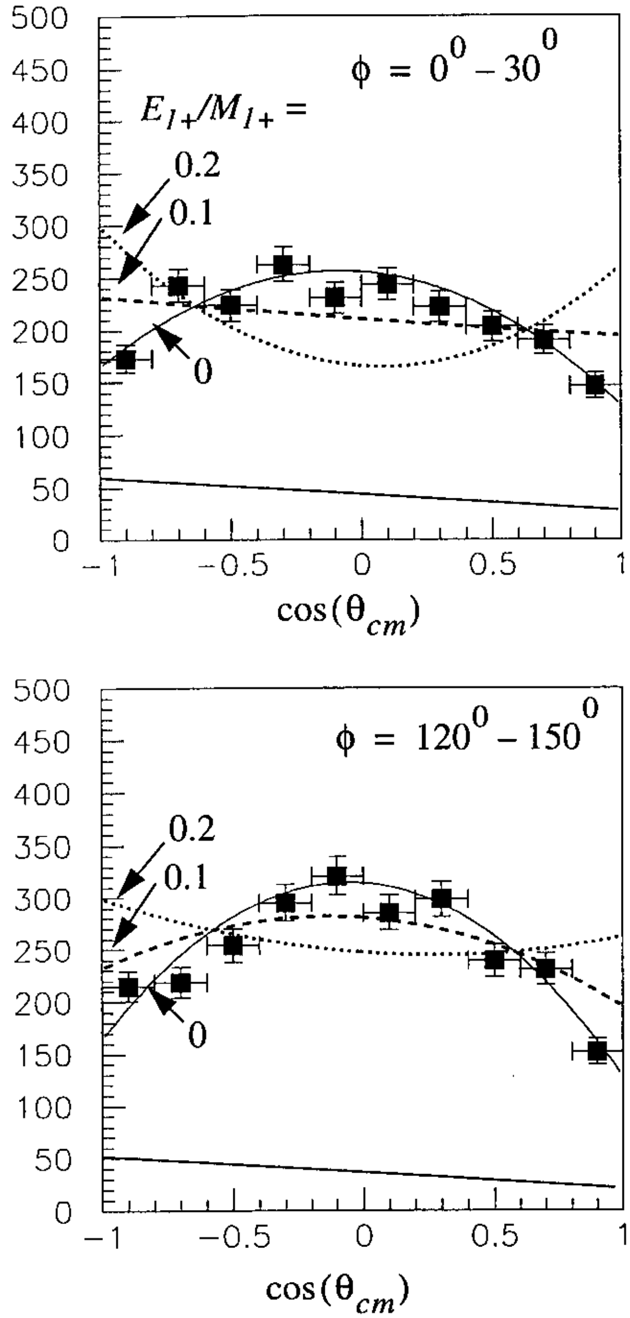

Figure 8. Simulated $p-\pi^0$ angular distributions for three bins in electroproduction at the peak of the $\Delta(1232)$. The three curves represent assumed values for E_{1+}/M_{1+} = 0, 0.1 and 0.2, including a model linear background as shown. This represents about 15% of the expected overall statistics in the $\Delta(1232)$ region. Comparable statistics would be expected for η production from the S_{11} (1535).

6. References

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