JLAB USER GROUP

Jefferson Lab PAC13
Proposal Cover Sheet

This document must be received by close of business Thursday, **December 18, 1997** at:

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

Experimental Hall: C

Days Requested for Approval: 15 + 25

☑ **New Proposal Title:** BARYON RESONANCE ELECTROPRODUCTION AT HIGH MOMENTUM TRANSFER

☐ **Update Experiment Number:**

☐ **Letter-of-Intent Title:**

(Choose one)

Proposal Physics Goals

Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

Contact Person

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JLab Use Only

Receipt Date: 12/14/97

By: [signature]

PR 97-101

BEAM REQUIREMENTS LIST

JLab Proposal No.: ____________________ Date: ____________

Hall: C Anticipated Run Date: ____________ PAC Approved Days: ____________

Spokesperson: P. Stoler
Phone: (518) 276 - 8388
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	5000	100		Liq. H_2 4 cm	240	300
2	6000	90		"	"	500

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.

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.

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:

* We plan to use only normally supplied laboratory equipment.

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	Electrical Equipment	Radioactive/Hazardous Materials
____ beamline magnets ____ analysis magnets ✓ target type: Liq H2 flow rate: ______ capacity: ______	____ cryo/electrical devices ____ capacitor banks ____ high voltage ____ exposed equipment	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: Liq H_2 tgt 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) Carbon (Graphite) BeO_2
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: ______ ______

Baryon Resonance Electroproduction at High Momentum Transfer

(Extension of TJNAF-CEBAF Experiment 94-014)

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

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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 Q^2 near 2.8 and 4 GeV^2/c^2. It is proposed to extend these measurements to $Q^2 = 5.7$ and 7.5 GeV^2/c^2 utilizing a 5 and 6 GeV electron beam energies respectively. 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 these exclusive reaction transition amplitudes between low Q^2 physics, where *soft* non-perturbative QCD processes characterized by constituent quarks dominate, to the high Q^2 regime where *hard* processes characterized by current quarks are expected to play an increasingly important role ,and eventually to where pQCD becomes important. Such measurements at these Q^2 were not possible before the existence of Jefferson Lab.

Reaction: $p(e, e'p)\pi^0, \eta$ @ $Q^2 \sim 5.7, 7.5$ GeV^2/c^2

E_{beam}	I_{max}	Target	beam time	proton detector	electron detector
5 GeV	100 μA	4cm LH_2	15 days	HMS	SOS
6 GeV	90 μA	4cm LH_2	25 days	HMS	SOS

1. Introduction

In experiment 94-014 the inelastic nucleon transition amplitudes to the $\Delta(1232)$ and $S_{11}(1535)$ baryon resonances were measured via the reactions $p(e,e'p)\pi^0$ and $p(e,e'p)\eta$ respectively in the previously inaccessible momentum transfer range $Q^2 = 2.8$ and 4 GeV^2/c^2. The quality of the data is excellent, enabling us to extract resonance amplitudes in a previously unexplored physical regime with very high statistical precision. Already in the case of the $\Delta(1232)$, the extracted amplitude M_{1+}, and the ratios E_{1+}/M_{1+} and S_{1+}/M_{1+} show we are not yet in the region of PQCD dominance, but beyond the range of the simple constituent quark model (CQM). Similar precision amplitudes have been extracted for the $S_{11}(1535)$. The excellent quality of the data, and the new physics they make accessible encourage us to propose to push the Q^2 frontier to 5.7 and 7.5 GeV^2/c^2 in two stages, utilizing electron beam energies of 5 and 6 GeV respectively when these energies become available. The body of data thus obtained will place tight constraints on quark/QCD based models in this Q^2 region.

The physics issues pertaining to this proposal relate to the non-perturbative structure of the hadron and the controversy about the relevant degrees of freedom of the reaction mechanisims 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 CQM is currently the most useful starting point. At the high Q^2 extreme, the smallest size and simplest Fock components of the hadron structure are 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.

There have been numerous theoretical attempts to describe the physics of exclusive reactions of baryons in this range of Q^2, ranging from models which evolve the CQM up in Q^2 employing relativity and quark form factors, evolving pQCD down in Q^2 employing valence quarks with form factors, and/or allowing for quark clusters, and QCD sum rule techniques which rely on duality between quark and hadron degrees of freedom, and finally using valence pQCD techniques. It is the purpose of this experiment to try to constrain the applicabilities of these various approaches.

2. Specific Physics Issues for the Proposed Experiment.

For the $\Delta(1232)$ the important specific issues which we would like to access are the magnitude and the Q^2 dependence of the dominant M_{1+}, and the relative contributions of E_{1+} and

S_{1+} amplitudes. For the $S_{11}(1535)$, the dominant E_{0+} and smaller S_{0+} in the η production channel are the quantities of interest.

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 highly ambiguous due to large inclusive backgrounds and the impossibility of extracting the relative resonant to non resonant contributions, and of course we get no information about the contributing multipoles.

An exclusive experiment allows us to extract information about the relative contributions of the M_{1+}, E_{1+} and S_{1+} amplitudes. The relationship between these is 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 data (Be-97) from Mainz bears this out. A theoretical fit by two of us (Da-97) find a ratio for the Δ to be $E_{1+}/M_{1+} = -.029 \pm .0023$. For $Q^2 > 0$, earlier data indicates this ratio remains small up to $Q^2 \sim 1$ GeV^2/c^2. Interestingly, the CQM which predicts M_{1+} dominance so well, fails to reproduce the magnitude of the M_{1+} amplitude to within 70 % of its measured value at $Q^2 = 0$, and has the wrong Q^2 shape as seen in the curve of Capstick and Keister (Ca-95) in Figure 1, whereas the addition of a phenomenological *quark form factor* by Carderelli et al. appears to improve the situation in the few GeV^2/c^2 region. Although the QCD sum rule calculations of Balyaev and Radyushkin (Ba-96) are in the right range, it is claimed (Ra-97) that improvement with respect to data should occur as Q^2 increases.

Figures 1a,b and c show the status of M_{1+}, E_{1+}/M_{1+} and S_{1+}/M_{1+}.

At high Q^2, according to valence pQCD only helicity-conserving amplitudes should contribute, leading to the prediction $E_{1+}/M_{1+} = 1$ and $S_{1+}/M_{1+} = 0$. 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.

At Q^2 of several GeV^2/c^2 there are models which have beed put forth as alternatives to pQCD which attempt to bridge the extremes of the CQM and valence pQCD.

The QCD sum rule based *local duality* procedure was developed 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-96), 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

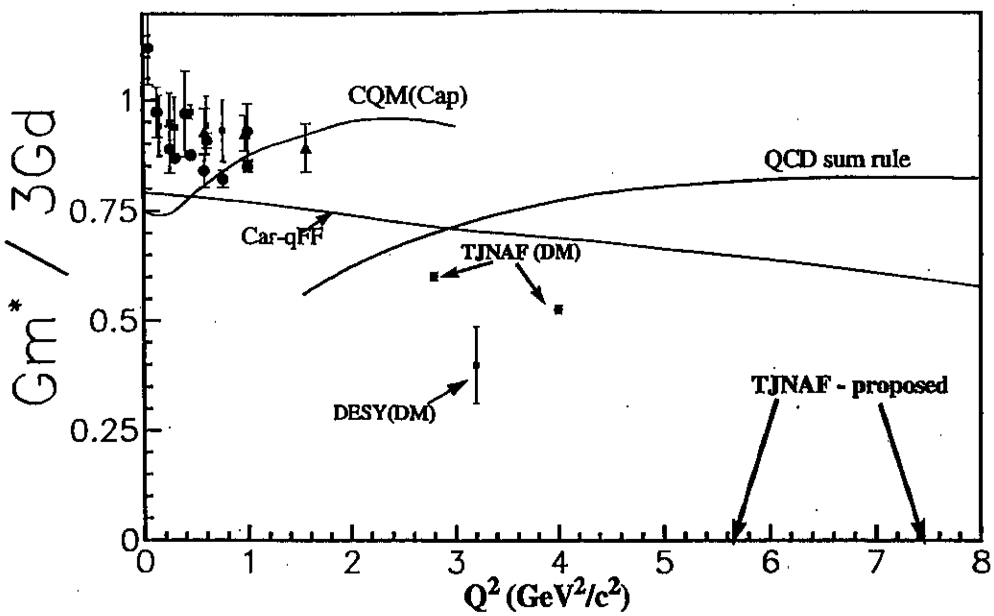

Figure 1a. The status of the form factor G^*_M for the M_{1+} amplitude as a function of Q^2. The data below Q^2= 1.5 are extractions from various earlier data sets. The point at 3.2 GeV^2/c^2 is the result of a theoretical fit by Da-97a to the earlier DESY data (Ha-79). The points at Q^2 = 2.8 and 4.0 GeV^2/c^2 are the preliminary results of the TJNAF experiment 94-014. The error bars shown reflect only the statistical precision, and do not include systematics. The curve denoted CQM(Cap) is the result of a relativistic quark model of Capstick and Keister (Ca-95). The curve denoted Car-qFF is the result of a relativistic quark model with the addition of a phenomenological *quark form factor* of Cardarelli et al. (Ca-96). The curve denoted *QCD sum rule* is due to Balayev and Radyushkin (Ba-96).

the pQCD value of +1. However, exclusive data in the multi-GeV^2/c^2 range is necessary to constrain the inputs of the model.

Another approach is the diquark model of Kroll et al.(Kr-92), which projects the formalisms of valence pQCD to the Q^2 range of interest here by allowing the virtual photons to be obsorbed by pairs of corellated valence quarks, which themselves have Q^2 dependent form factors. Again, calculations are presented for the three $\Delta(1232)$ amplitudes, and the $S_{11}(1535)$ amplitudes in the several GeV^2/c^2 region, with a number of model quark distribution functions. However, no previous data exist to test these hypotheses.

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

The situation for the $S_{11}(1535)$ is that the form factor for the S$_{11}$(1535) decays much more slowly than those for the proton or other resonances at lower Q^2. Although the $D_{13}(1520)$ is dominant at Q^2 = 0, exclusive data taken up to 3 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.

There is also a great deal of controversy about the width of the $S_{11}(1535)$. Recent analysis at Q^2 = 0 by Mainz and RPI groups give widths near 200 MeV. On the other hand, analyses

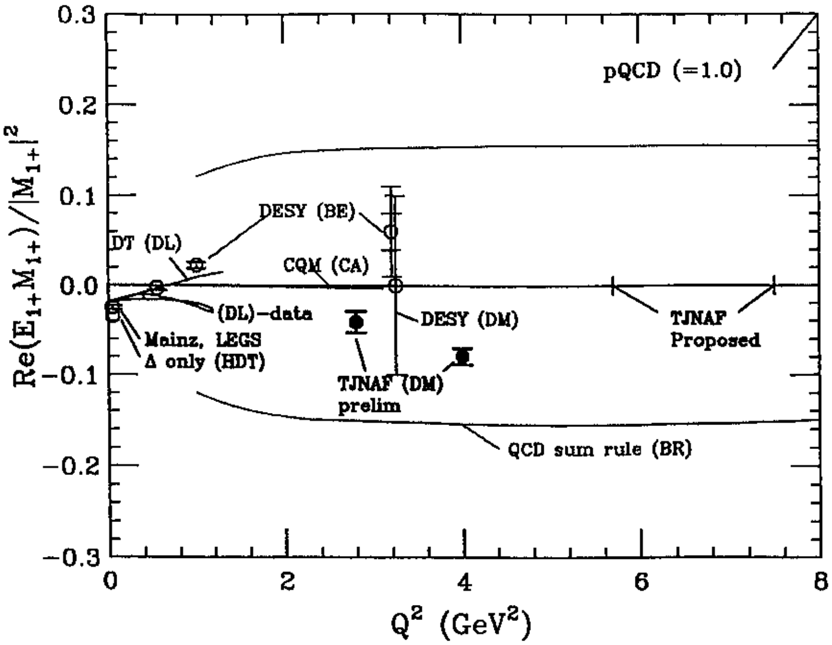

Figure 1b. The ratio E_{1+}/M_{1+} (or $E2/M1$) as a function of Q^2. The data at Q^2=0, labelled Mainz, is from Be-97, and that labelled LEGS is from Bl-20. The data near Q^2=0.5 and 1 GeV^2/c^2 as well as that labelled BE at 3.2 GeV^2/c^2 are due to an analysis by Bu-95 of earlier data from DESY (Ha-79). 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 due to a quark model calculation from Ca-92. The predicted pQCD result is off scale at $E_{1+}/M_{1+} = 1$. The two data points at Q^2= 2.8 and 4 GeV^2/c^2, correspond to an analysis of the recent Hall C experiment 94-014. The error are statistical. Also shown are the Q^2 points of the current proposal, at Q^2 = 5.7 and 7.5 GeV^2/c^2

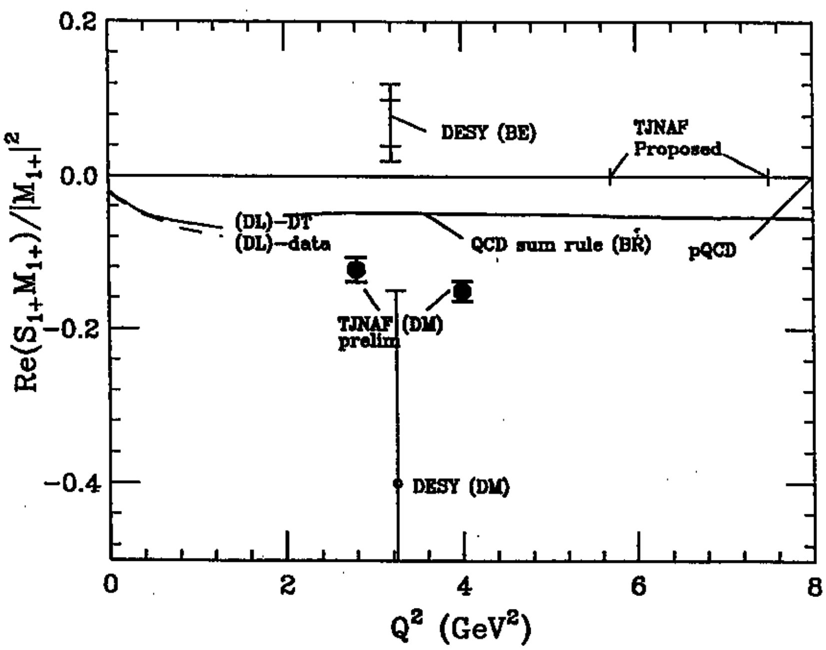

Figure 1c.The ratio S_{1+}/M_{1+} (or S_1/M_1) as a function of Q^2.

of higher Q^2 data (Brasse, Stoler) appear to be consistent with a width $\sim$ 100 MeV. The initial analysis of 94-014 appears to be consistent with the lower value, and gives a cross section which is consistent with the earlier DESY data (Brasse) as shown in Figure 2.

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 models will be strongly tested by higher Q^2 data. 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, particularly at high Q^2, since, as mentioned above, the $D_{13}(1520)$ form factor may be falling faster than the $S_{11}(1535)$. Already at $Q^2 = 3\,(\mathrm{GeV}/c)^2$, the $S_{11}(1535)$ appears to dominate the cross section. Above this point, the cross section 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 5.7 and 7.5 $\mathrm{GeV}^2/\mathrm{c}^2$ 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. The expansion coefficients $A_{l\pm}$ and $B_{l\pm}$ are the transverse partial wave helicity 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

Experiment 94-014 measured the reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$ at $Q^2 = 2.8$ and 4 $\mathrm{GeV}^2/\mathrm{c}^2$, $p(e,e'p)\eta^0$ from the $S_{11}(1535)$ at $Q^2 = 2.4$ and 3.6 $\mathrm{GeV}^2/\mathrm{c}^2$, with electron energies 3.2 and 4.0 GeV respectively. The experiment utilized about 200 hrs of beam at a current of about 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

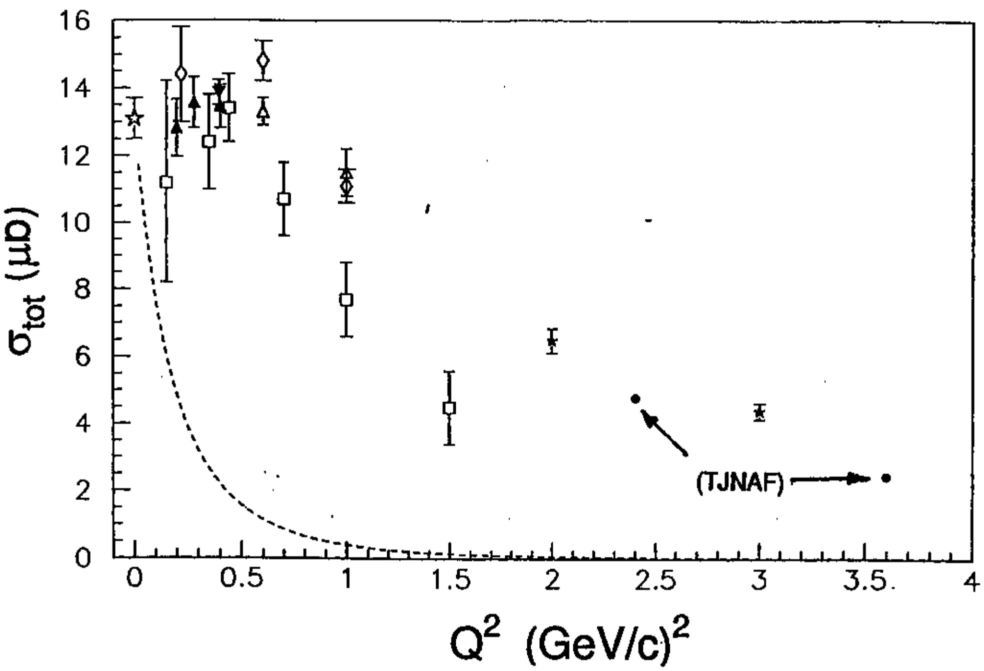

Figure 2. The virtual photon cross section for the excitation of the $S_{11}(1535)$. The preliminary TJNAF 94-014 cross sections at Q^2=2.4 and 3.6 GeV^2/c^2 are also shown as filled circles. The the errors are statistical, and are smaller than the size of the circles.

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 as an example.

The reconstructed c.m. decay angles are typically about $\delta\phi \sim 3°$ and $\delta(cos\theta) \sim .04$. For the Δ the 2 pion background is totally eliminated, whereas for the S_{11} only a small multipion background remains. As an example, a subset of the total obtained angular distributions at $Q^2 \sim 2.8$ GeV^2/c^2 for several intervals of W and $\phi - out - of - plane$ is shown in Figures 5.

Global fits to the data have been carried out by Davidson and Mukhopadhyay (theoretical collaborators on this experiment), using a fully unitarized effective Lagrangian approach to extract G^*_M (ie. $|M_{1+}|$), $Re(E^*_{1+}M_{1+})/|M_{1+}|^2$, and $Re(S^*_{1+}M_{1+})/|M_{1+}|^2$, and the results are displayed in Figures 1a, 1b and 1c.

4. Proposed Experiment

The excellent quality of the data encourages us to propose to push the Q^2 frontier to $Q^2 = 5.7$ GeV^2/c^2, and then 7.5 GeV^2/c^2 utilizing electron beam energies of 5 and 6 GeV respectively in two separated run periods. The experiment, as in 94-014, will measure the

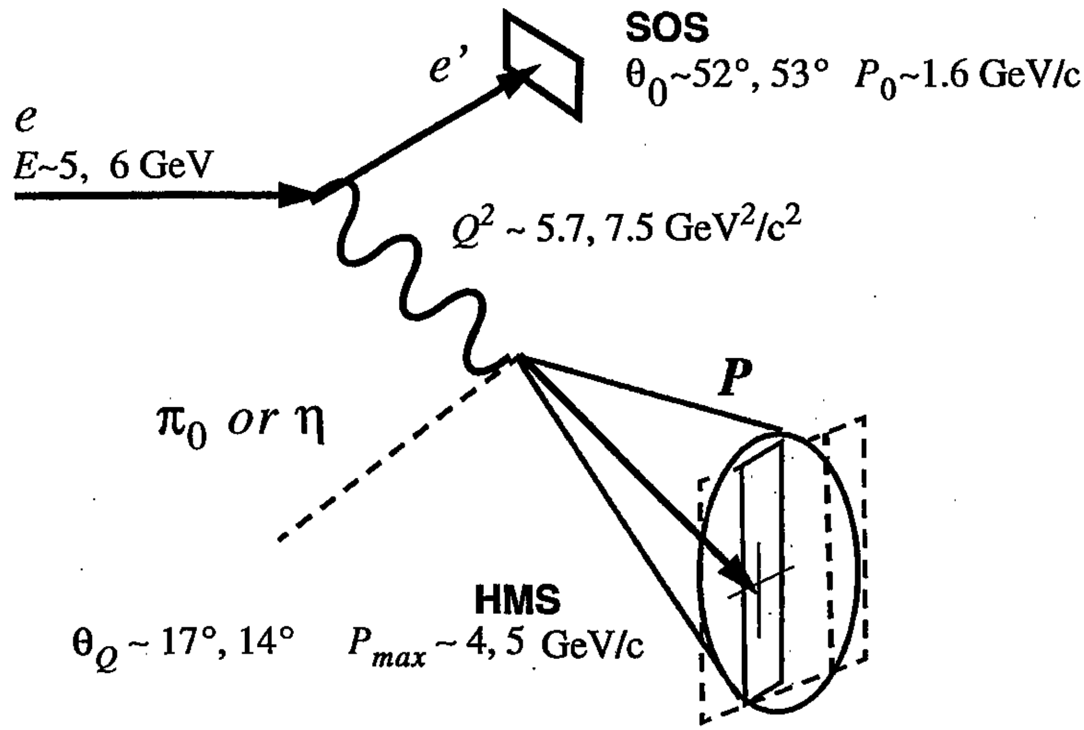

Figure 3. The kinematics of the experiment.

reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$, and $p(e,e'p)\eta$ from the $S_{11}(1535)$.

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 for each run interval, 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 5.5 and 7.5 GeV^2/c^2 results in a successively 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} at intervals of W near the $\Delta(1232)$ are shown in Figures 6.

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 % for each step in Q^2, which makes it 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 modelling of the radiative and multipion backgrounds, which are in progress in connection with E94-014, become more important. Since the SOS angular resolution is the biggest contributor to

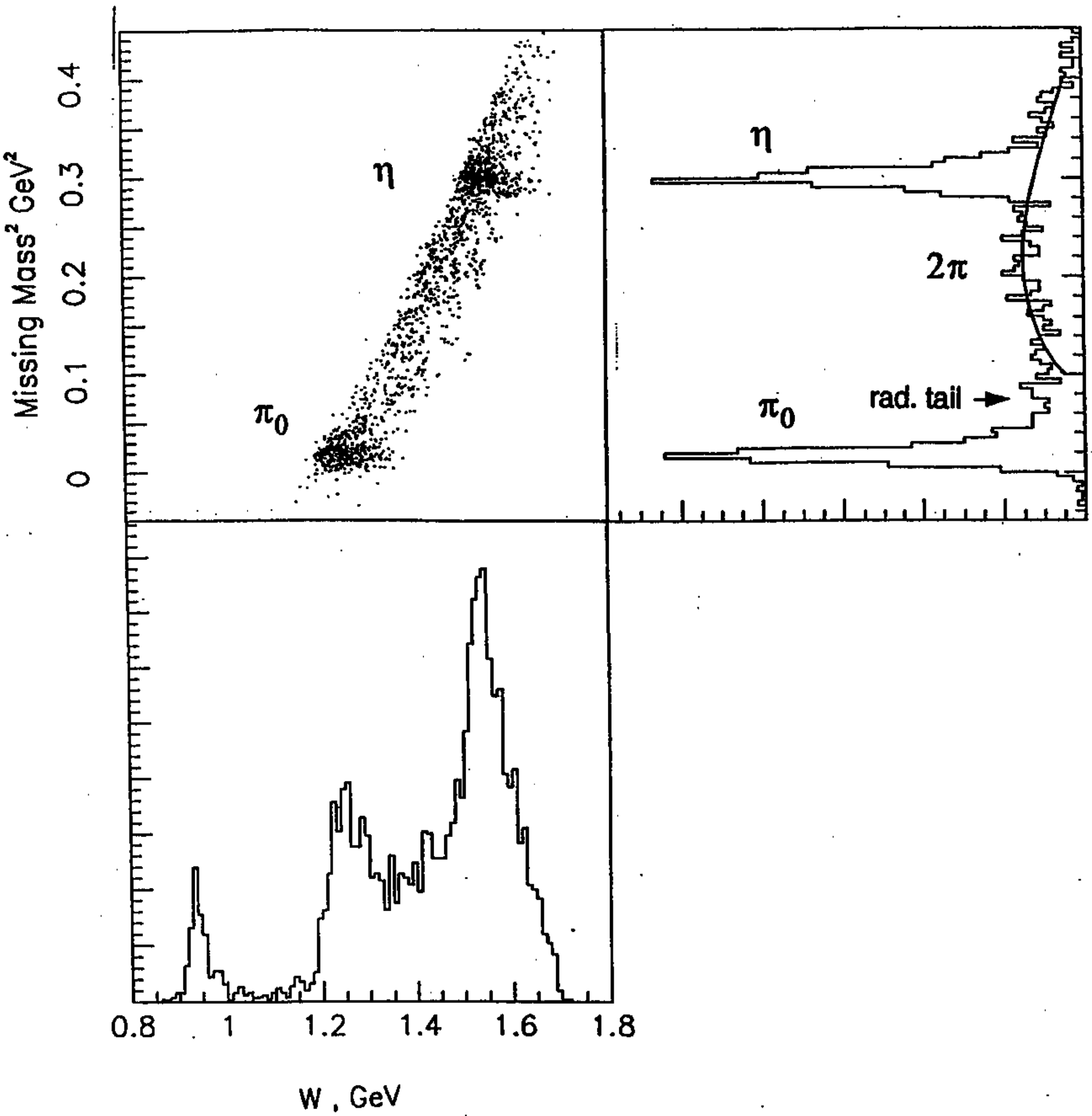

Figure 4. Missing mass squared m^2 vs. W for the reaction $p(e,e'p)$ obtained in experiment 94-014. This corresponds to one kinematic setting in θ_0^{HMS} and P_0^{HMS}. The π^0 and η reconstructions are clearly visible in the projection on the m^2 axis on the right, as is the multipion continuum. The 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.

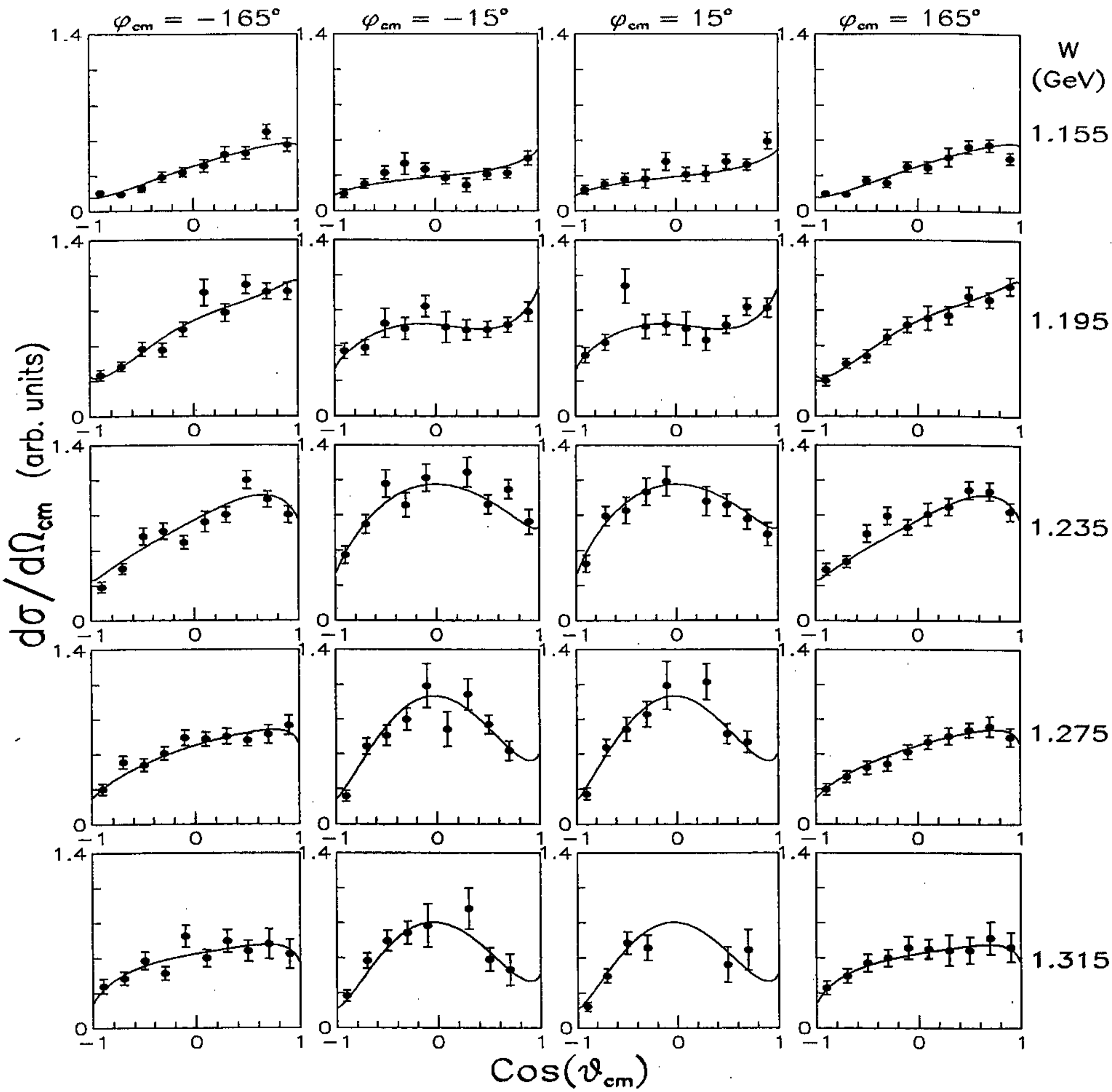

Figure 5. Preliminary center of mass angular distribution for π^0 production at the delta resonance, for selected kinematic intervals of W and out of plane angles ϕ at Q^2= 2.8 GeV^2/c^2, obtained in experiment 94-014. The curves represent a global fit in terms of multipoles, up to p waves, and assuming M_{1+} dominance.

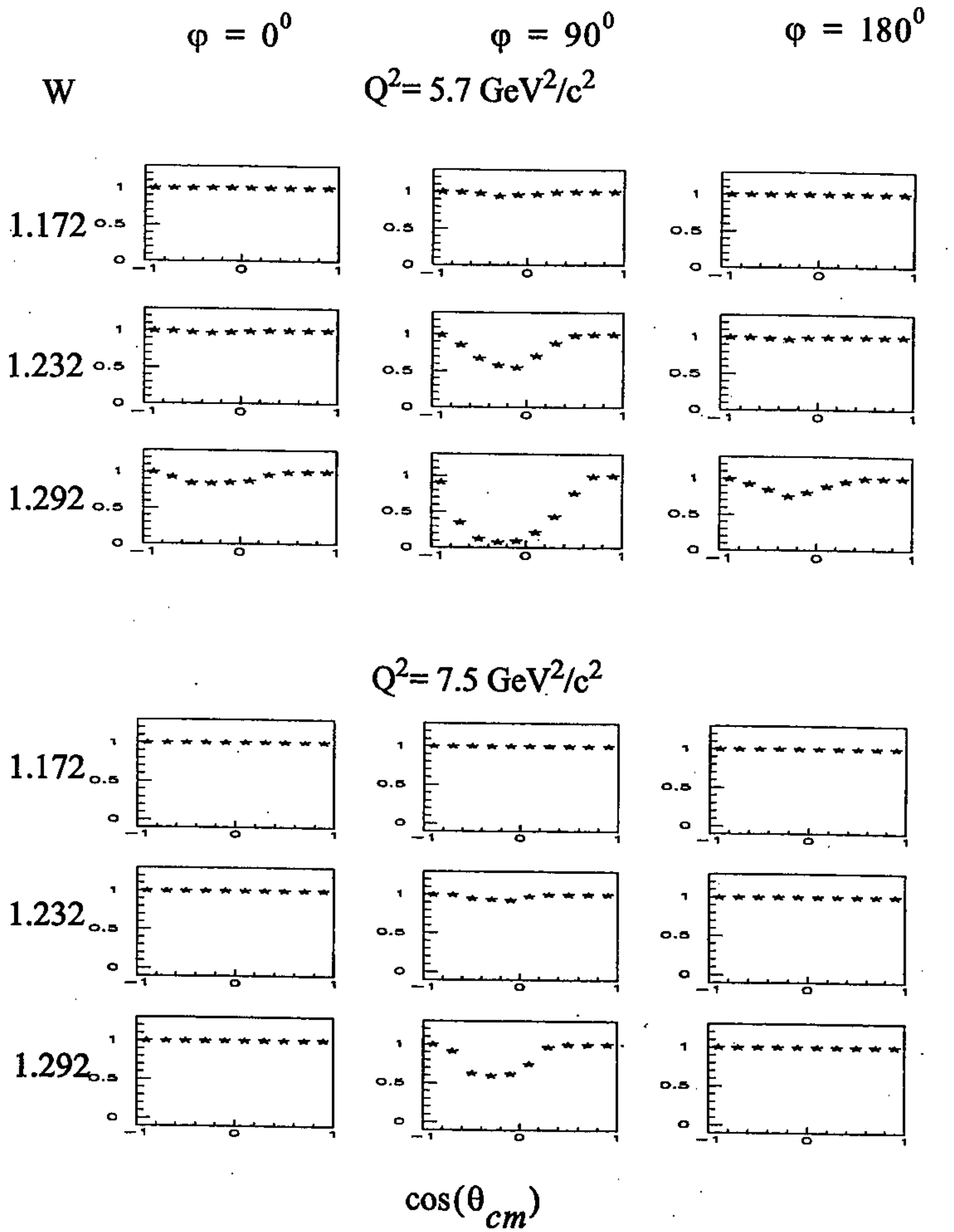

Figure 6. The calculated acceptance function for the reaction $p(e,e'p)\pi^0$ at three values of out of plane angle $\phi = 0°, 90°$, and $180°$ at three values of W for $Q^2 = 5.7$ and 7.5 GeV^2/c^2 respectively.

the reconstruction resolutions in E94-014, for the $Q^2 = 7.5$ GeV^2/c^2 run we will consider decreasing the quadrupole field and thereby improve angular resolution at the expense of some acceptance.

At $Q^2 = 5.7$ GeV, using a current of 100 μA incident on the Hall C 4 cm liquid hydrogen target, we expect to collect about 25,000 events for each resonance simultaneousely in 15 days of running.

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

For the entire 5 GeV portion ($Q^2 \sim 5.7$ GeV^2/c^2) of the experiment the SOS momentum and angle will be fixed at $P_0 = 1.6$ GeV/c, $\theta_0 = 50°$.

For the 6 GeV phase of the experiment ($Q^2 \sim 7.6$ GeV^2/c^2.) the SOS momentum and angle will be fixed at $P_0 = 1.6$ GeV/c, $\theta_0 = 53°$. Table 1 shows the proposed HMS angular and momentum settings.

Electrons (SOS)				Protons (HMS)			
Q^2	E_{beam}	E'_0	θ'_0	P_{max}	P_{min}	θ_Q	$P-\theta$ settings
5.7 GeV^2/c^2	5 GeV	1.6 GeV	50°	4.0 GeV/c	2.4 GeV/c	17°	18
7.6 GeV^2/c^2	6 GeV	1.6 GeV	53°	5.1 GeV/c	3.1 GeV/c	14°	10

6. References

Ba-96 Belyaev VM, Radyushkin AV. *Phys. Rev.* D53:6509 (1996)

Be-97 R. Beck et al., Phys. Rev. Lett., **78**, 606 (1995)

Bl-92 G. S. Blanpied et al., Phys. Rev. Lett., **69**, 1880 (1992).

Br-84 F.W. Brasse et al., Z. Phys. **C22**, 33 (1984).

Bu-95 V. Burkert and L. Elouadrhiri, Phys. Rev. Lett., **75**, 3614 (1995)

Ca-95 S. Capstick and B. Keister, Phys. Rev. **D51**, 3598 (1995).

Ca-96 F. Cardielli et al., Physics Letters **B371**, 7 (1996)

Da-97 R. Davidson and N. Mukhopadhyay, Phys. Rev. Lett. **79**, 4509 (1997)

Da-97a R. Davidson, private communication.

Ha-79 R. Haiden, DESY Report No. F21-79-03, unpublished, (1979)

Da-97 R. Davidson and N. C. Mukhopadhyay, private communication.

Kr-92 P. Kroll, M. Schurman, and W. Schweiger, Z. Phys. **A342**, 429 (1992)

Baryon Resonance Electroproduction at High Momentum Transfer

(Extension of TJNAF-CEBAF Experiment 94-014)

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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 Q^2 near 2.8 and 4 GeV^2/c^2. It is proposed to extend these measurements to $Q^2 = 5.7$ and 7.5 GeV^2/c^2 utilizing a 5 and 6 GeV electron beam energies respectively. 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 these exclusive reaction transition amplitudes between low Q^2 physics, where *soft* non-perturbative QCD processes characterized by constituent quarks dominate, to the high Q^2 regime where *hard* processes characterized by current quarks are expected to play an increasingly important role ,and eventually to where pQCD becomes important. Such measurements at these Q^2 were not possible before the existence of Jefferson Lab.

Reaction: $p(e, e'p)\pi^0, \eta$ @ $Q^2 \sim 5.7, 7.5$ GeV^2/c^2

E_{beam}	I_{max}	Target	beam time	proton detector	electron detector
5 GeV	100 μA	4cm LH_2	15 days	HMS	SOS
6 GeV	90 μA	4cm LH_2	25 days	HMS	SOS

1. Introduction

In experiment 94-014 the inelastic nucleon transition amplitudes to the $\Delta(1232)$ and $S_{11}(1535)$ baryon resonances were measured via the reactions $p(e,e'p)\pi^0$ and $p(e,e'p)\eta$ respectively in the previously inaccessible momentum transfer range $Q^2 = 2.8$ and 4 GeV^2/c^2. The quality of the data is excellent, enabling us to extract resonance amplitudes in a previously unexplored physical regime with very high statistical precision. Already in the case of the $\Delta(1232)$, the extracted amplitude M_{1+}, and the ratios E_{1+}/M_{1+} and S_{1+}/M_{1+} show we are not yet in the region of PQCD dominance, but beyond the range of the simple constituent quark model (CQM). Similar precision amplitudes have been extracted for the $S_{11}(1535)$. The excellent quality of the data, and the new physics they make accessible encourage us to propose to push the Q^2 frontier to 5.7 and 7.5 GeV^2/c^2 in two stages, utilizing electron beam energies of 5 and 6 GeV respectively when these energies become available. The body of data thus obtained will place tight constraints on quark/QCD based models in this Q^2 region.

The physics issues pertaining to this proposal relate to the non-perturbative structure of the hadron and the controversy about the relevant degrees of freedom of the reaction mechanisims 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 CQM is currently the most useful starting point. At the high Q^2 extreme, the smallest size and simplest Fock components of the hadron structure are 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.

There have been numerous theoretical attempts to describe the physics of exclusive reactions of baryons in this range of Q^2, ranging from models which evolve the CQM up in Q^2 employing relativity and quark form factors, evolving pQCD down in Q^2 employing valence quarks with form factors, and/or allowing for quark clusters, and QCD sum rule techniques which rely on duality between quark and hadron degrees of freedom, and finally using valence pQCD techniques. It is the purpose of this experiment to try to constrain the applicabilities of these various approaches.

2. Specific Physics Issues for the Proposed Experiment.

For the $\Delta(1232)$ the important specific issues which we would like to access are the magnitude and the Q^2 dependence of the dominant M_{1+}, and the relative contributions of E_{1+} and

S_{1+} amplitudes. For the $S_{11}(1535)$, the dominant E_{0+} and smaller S_{0+} in the η production channel are the quantities of interest.

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 highly ambiguous due to large inclusive backgrounds and the impossibility of extracting the relative resonant to non resonant contributions, and of course we get no information about the contributing multipoles.

An exclusive experiment allows us to extract information about the relative contributions of the M_{1+}, E_{1+} and S_{1+} amplitudes. The relationship between these is 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 $N \rightarrow \Delta$ 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 data (Be-97) from Mainz bears this out. A theoretical fit by two of us (Da-97) find a ratio for the Δ to be $E_{1+}/M_{1+} = -.029 \pm .0023$. For $Q^2 > 0$, earlier data indicates this ratio remains small up to $Q^2 \sim 1$ GeV^2/c^2. Interestingly, the CQM which predicts M_{1+} dominance so well, fails to reproduce the magnitude of the M_{1+} amplitude to within 70 % of its measured value at $Q^2 = 0$, and has the wrong Q^2 shape as seen in the curve of Capstick and Keister (Ca-95) in Figure 1, whereas the addition of a phenomenological *quark form factor* by Carderelli et al. appears to improve the situation in the few GeV^2/c^2 region. Although the QCD sum rule calculations of Balyaev and Radyushkin (Ba-96) are in the right range, it is claimed (Ra-97) that improvement with respect to data should occur as Q^2 increases.

Figures 1a,b and c show the status of M_{1+}, E_{1+}/M_{1+} and S_{1+}/M_{1+}.

At high Q^2, according to valence pQCD only helicity-conserving amplitudes should contribute, leading to the prediction $E_{1+}/M_{1+} = 1$ and $S_{1+}/M_{1+} = 0$. 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.

At Q^2 of several GeV^2/c^2 there are models which have beed put forth as alternatives to pQCD which attempt to bridge the extremes of the CQM and valence pQCD.

The QCD sum rule based *local duality* procedure was developed 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-96), 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

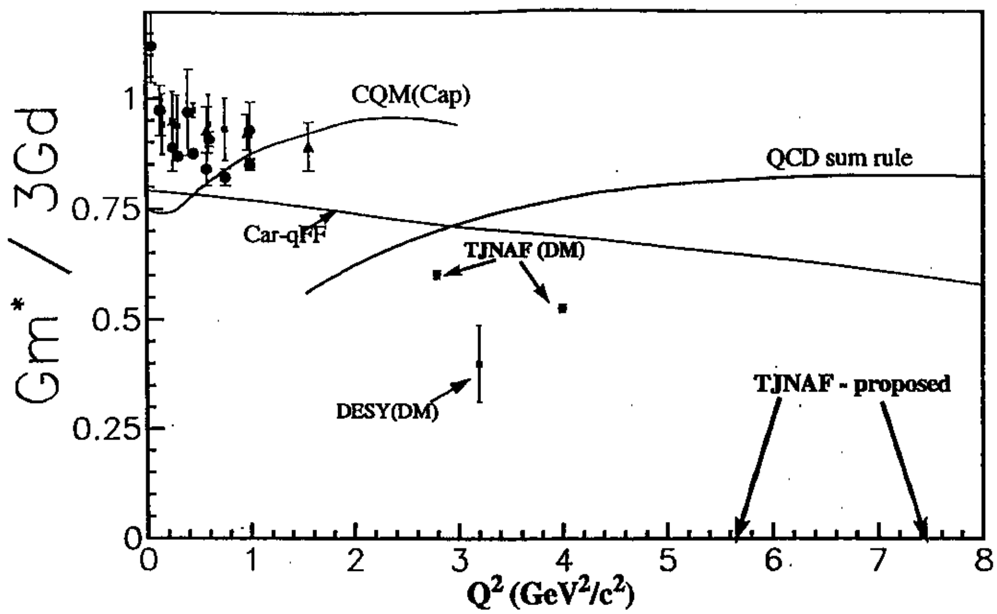

Figure 1a. The status of the form factor G^*_M for the M_{1+} amplitude as a function of Q^2. The data below $Q^2 = 1.5$ are extractions from various earlier data sets. The point at 3.2 GeV^2/c^2 is the result of a theoretical fit by Da-97a to the earlier DESY data (Ha-79). The points at $Q^2 = 2.8$ and 4.0 GeV^2/c^2 are the preliminary results of the TJNAF experiment 94-014. The error bars shown reflect only the statistical precision, and do not include systematics. The curve denoted CQM(Cap) is the result of a relativistic quark model of Capstick and Keister (Ca-95). The curve denoted Car-qFF is the result of a relativistic quark model with the addition of a phenomenological *quark form factor* of Cardarelli et al. (Ca-96). The curve denoted *QCD sum rule* is due to Balayev and Radyushkin (Ba-96).

the pQCD value of +1. However, exclusive data in the multi-GeV^2/c^2 range is necessary to constrain the inputs of the model.

Another approach is the diquark model of Kroll et al.(Kr-92), which projects the formalisms of valence pQCD to the Q^2 range of interest here by allowing the virtual photons to be obsorbed by pairs of corellated valence quarks, which themselves have Q^2 dependent form factors. Again, calculations are presented for the three $\Delta(1232)$ amplitudes, and the $S_{11}(1535)$ amplitudes in the several GeV^2/c^2 region, with a number of model quark distribution functions. However, no previous data exist to test these hypothoses.

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

The situation for the $S_{11}(1535)$ is that the form factor for the $S_{11}(1535)$ decays much more slowly than those for the proton or other resonances at lower Q^2. Although the $D_{13}(1520)$ is dominant at $Q^2 = 0$, exclusive data taken up to 3 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.

There is also a great deal of controversy about the width of the $S_{11}(1535)$. Recent analysis at $Q^2 = 0$ by Mainz and RPI groups give widths near 200 MeV. On the other hand, analyses

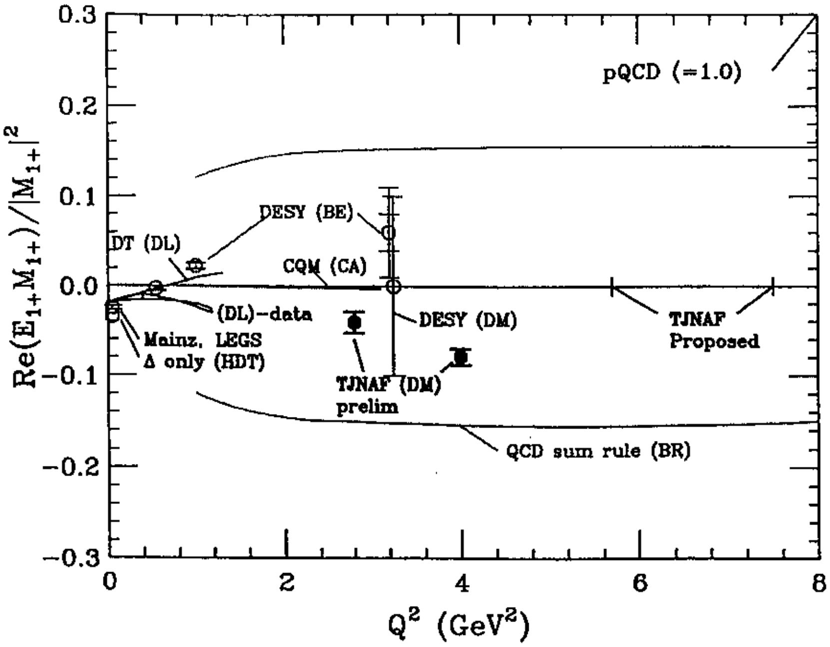

Figure 1b. The ratio E_{1+}/M_{1+} (or $E2/M1$) as a function of Q^2. The data at Q^2=0, labelled Mainz, is from Be-97, and that labelled LEGS is from Bl-20. The data near Q^2=0.5 and 1 GeV^2/c^2 as well as that labelled BE at 3.2 GeV^2/c^2 are due to an analysis by Bu-95 of earlier data from DESY (Ha-79). 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 due to a quark model calculation from Ca-92. The predicted pQCD result is off scale at $E_{1+}/M_{1+} = 1$. The two data points at Q^2= 2.8 and 4 GeV^2/c^2, correspond to an analysis of the recent Hall C experiment 94-014. The error are statistical. Also shown are the Q^2 points of the current proposal, at Q^2 = 5.7 and 7.5 GeV^2/c^2

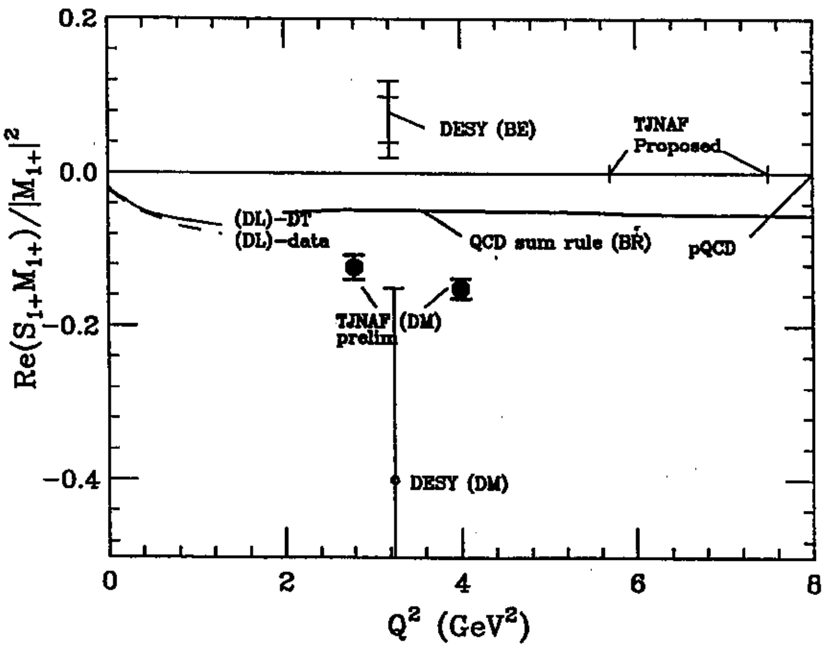

Figure 1c.The ratio S_{1+}/M_{1+} (or S_1/M_1) as a function of Q^2.

of higher Q^2 data (Brasse, Stoler) appear to be consistent with a width $\sim$ 100 MeV. The initial analysis of 94-014 appears to be consistent with the lower value, and gives a cross section which is consistent with the earlier DESY data (Brasse) as shown in Figure 2.

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 models will be strongly tested by higher Q^2 data. 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, particularly at high Q^2, since, as mentioned above, the $D_{13}(1520)$ form factor may be falling faster than the $S_{11}(1535)$. Already at $Q^2 = 3\,(\mathrm{GeV}/c)^2$, the $S_{11}(1535)$ appears to dominate the cross section. Above this point, the cross section 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 5.7 and 7.5 $\mathrm{GeV}^2/\mathrm{c}^2$ 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. The expansion coefficients $A_{l\pm}$ and $B_{l\pm}$ are the transverse partial wave helicity 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

Experiment 94-014 measured the reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$ at $Q^2 = 2.8$ and 4 $\mathrm{GeV}^2/\mathrm{c}^2$, $p(e,e'p)\eta^0$ from the $S_{11}(1535)$ at $Q^2 = 2.4$ and 3.6 $\mathrm{GeV}^2/\mathrm{c}^2$, with electron energies 3.2 and 4.0 GeV respectively. The experiment utilized about 200 hrs of beam at a current of about 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

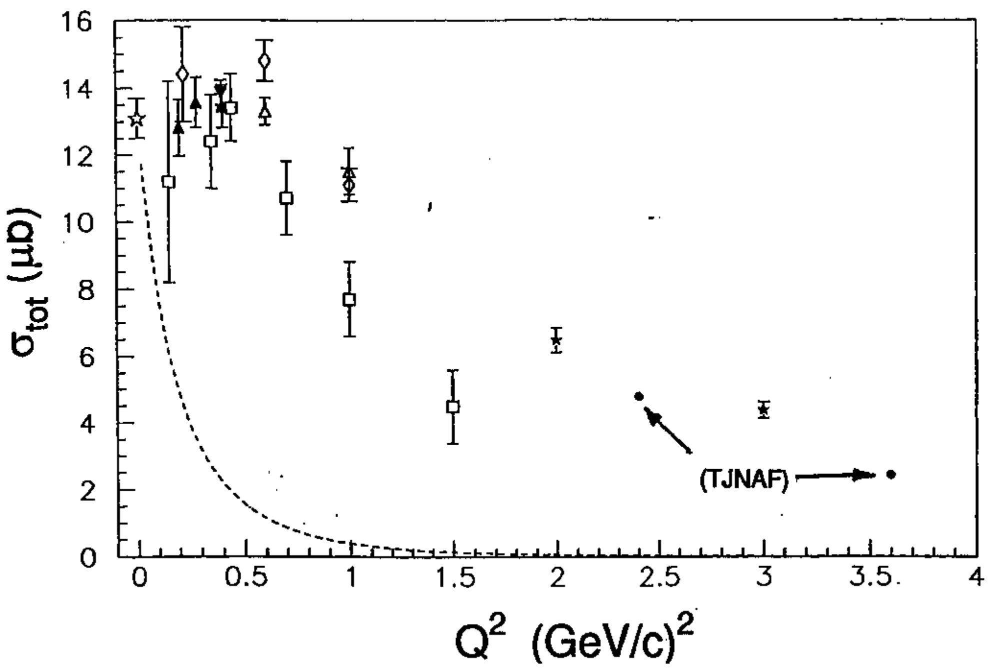

Figure 2. The virtual photon cross section for the excitation of the $S_{11}(1535)$. The preliminary TJNAF 94-014 cross sections at Q^2=2.4 and 3.6 GeV^2/c^2 are also shown as filled circles. The the errors are statistical, and are smaller than the size of the circles.

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 as an example.

The reconstructed c.m. decay angles are typically about $\delta\phi \sim 3°$ and $\delta(cos\theta) \sim .04$. For the Δ the 2 pion background is totally eliminated, whereas for the S_{11} only a small multipion background remains. As an example, a subset of the total obtained angular distributions at $Q^2 \sim 2.8$ GeV^2/c^2 for several intervals of W and $\phi - out - of - plane$ is shown in Figures 5.

Global fits to the data have been carried out by Davidson and Mukhopadhyay (theoretical collaborators on this experiment), using a fully unitarized effective Lagrangian approach to extract G^*_M (ie. $|M_{1+}|$), $Re(E^*_{1+}M_{1+})/|M_{1+}|^2$, and $Re(S^*_{1+}M_{1+})/|M_{1+}|^2$, and the results are displayed in Figures 1a, 1b and 1c.

4. Proposed Experiment

The excellent quality of the data encourages us to propose to push the Q^2 frontier to $Q^2 = 5.7$ GeV^2/c^2, and then 7.5 GeV^2/c^2 utilizing electron beam energies of 5 and 6 GeV respectively in two separated run periods. The experiment, as in 94-014, will measure the

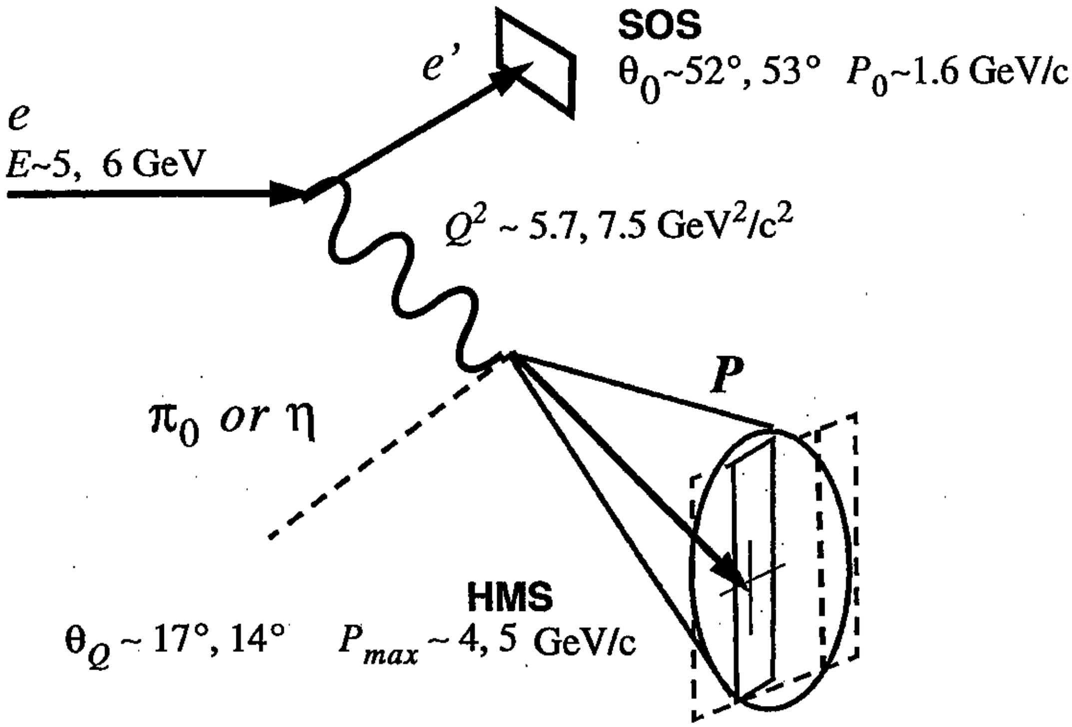

Figure 3. The kinematics of the experiment.

reactions $p(e,e'p)\pi^0$ from the $\Delta(1232)$, and $p(e,e'p)\eta$ from the $S_{11}(1535)$.

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 for each run interval, 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 5.5 and 7.5 GeV^2/c^2 results in a successively 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} at intervals of W near the $\Delta(1232)$ are shown in Figures 6.

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 % for each step in Q^2, which makes it 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 modelling of the radiative and multipion backgrounds, which are in progress in connection with E94-014, become more important. Since the SOS angular resolution is the biggest contributor to

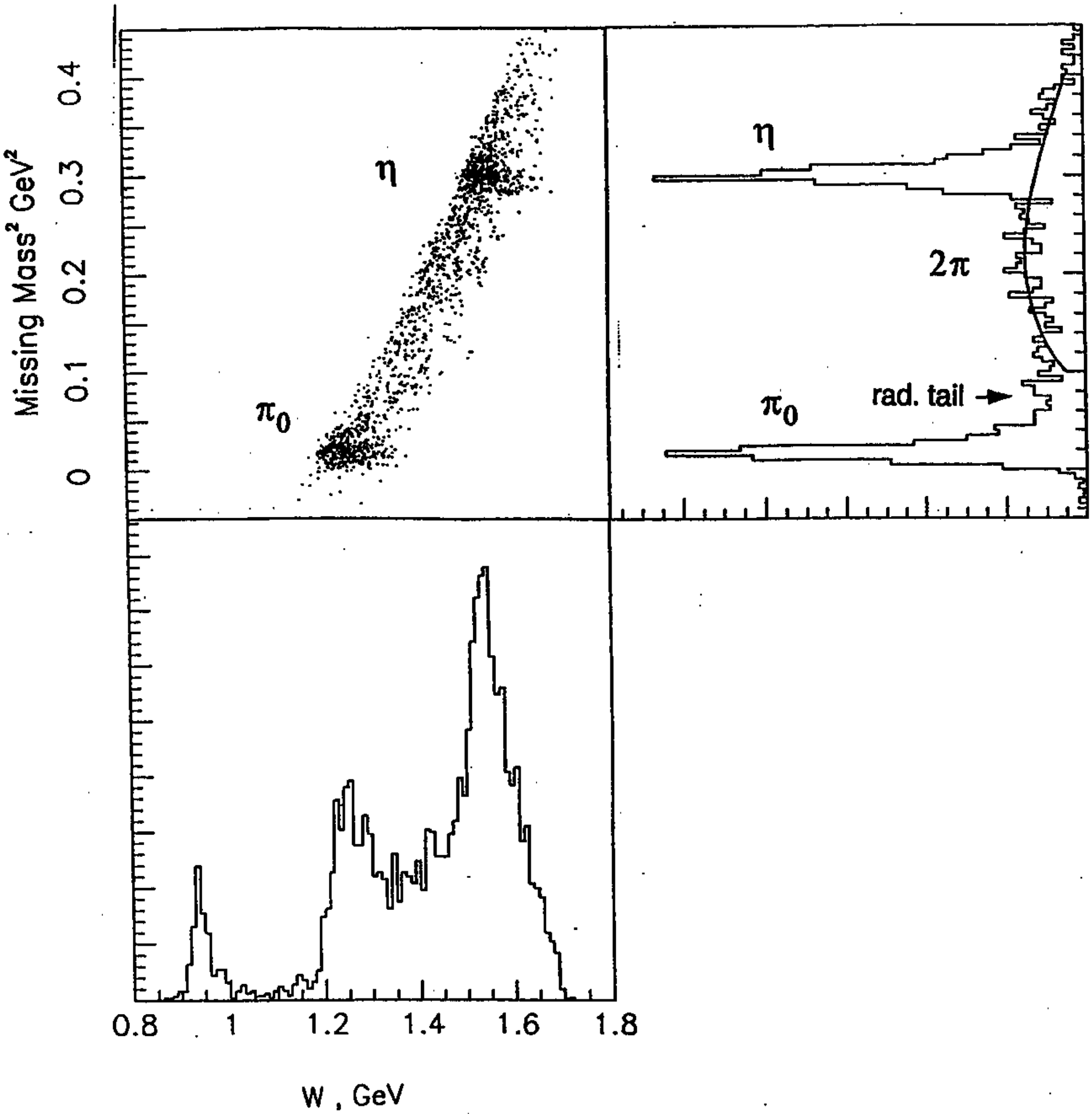

Figure 4. Missing mass squared m^2 vs. W for the reaction $p(e,e'p)$ obtained in experiment 94-014. This corresponds to one kinematic setting in θ_0^{HMS} and P_0^{HMS}. The π^0 and η reconstructions are clearly visible in the projection on the m^2 axis on the right, as is the multipion continuum. The 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.

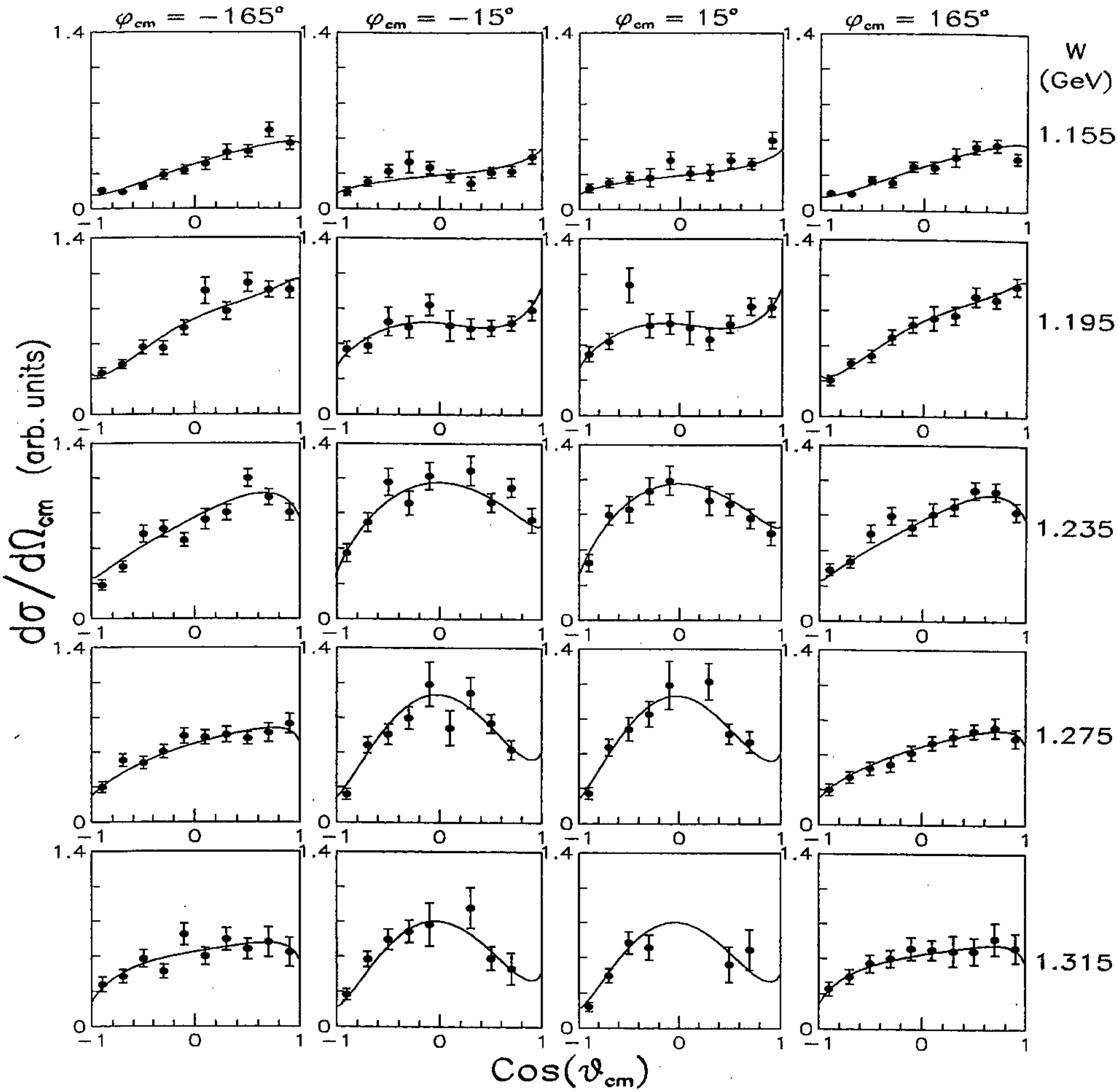

Figure 5. Preliminary center of mass angular distribution for π^0 production at the delta resonance, for selected kinematic intervals of W and out of plane angles ϕ at Q^2= 2.8 GeV^2/c^2, obtained in experiment 94-014. The curves represent a global fit in terms of multipoles, up to p waves, and assuming M_{1+} dominance.

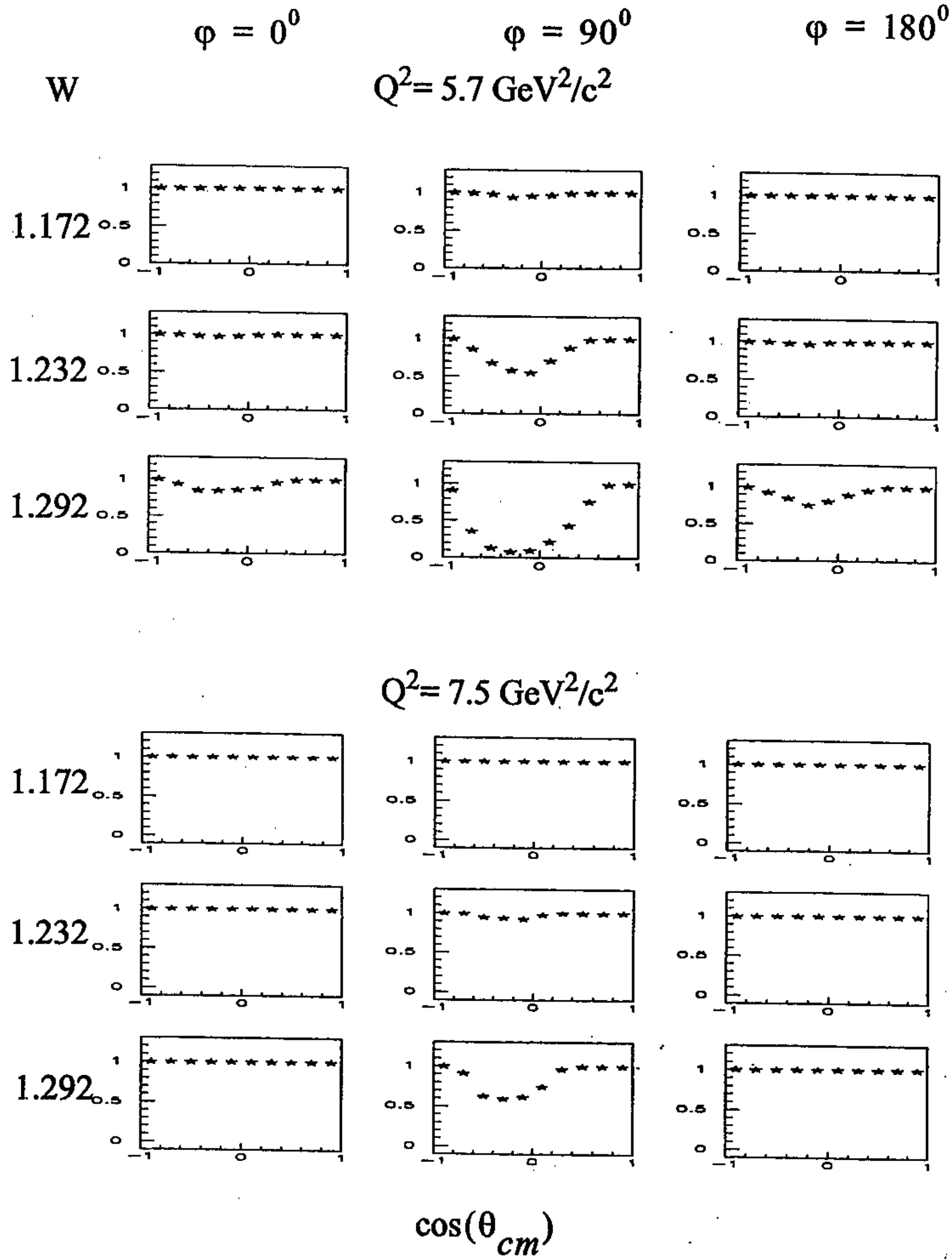

Figure 6. The calculated acceptance function for the reaction $p(e,e'p)\pi^0$ at three values of out of plane angle $\phi = 0°, 90°$, and $180°$ at three values of W for $Q^2 = 5.7$ and 7.5 GeV^2/c^2 respectively.

the reconstruction resolutions in E94-014, for the $Q^2 = 7.5$ GeV^2/c^2 run we will consider decreasing the quadrupole field and thereby improve angular resolution at the expense of some acceptance.

At $Q^2 = 5.7$ GeV, using a current of 100 μA incident on the Hall C 4 cm liquid hydrogen target, we expect to collect about 25,000 events for each resonance simultaneousely in 15 days of running.

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

For the entire 5 GeV portion ($Q^2 \sim 5.7$ GeV^2/c^2) of the experiment the SOS momentum and angle will be fixed at $P_0 = 1.6$ GeV/c, $\theta_0 = 50°$.

For the 6 GeV phase of the experiment ($Q^2 \sim 7.6$ GeV^2/c^2.) the SOS momentum and angle will be fixed at $P_0 = 1.6$ GeV/c, $\theta_0 = 53°$. Table 1 shows the proposed HMS angular and momentum settings.

Electrons (SOS)				Protons (HMS)			
Q^2	E_{beam}	E'_0	θ'_0	P_{max}	P_{min}	θ_Q	$P-\theta$ settings
5.7 GeV^2/c^2	5 GeV	1.6 GeV	50°	4.0 GeV/c	2.4 GeV/c	17°	18
7.6 GeV^2/c^2	6 GeV	1.6 GeV	53°	5.1 GeV/c	3.1 GeV/c	14°	10

6. References

Ba-96 Belyaev VM, Radyushkin AV. *Phys. Rev.* D53:6509 (1996)

Be-97 R. Beck et al., Phys. Rev. Lett., **78**, 606 (1995)

Bl-92 G. S. Blanpied et al., Phys. Rev. Lett., **69**, 1880 (1992).

Br-84 F.W. Brasse et al., Z. Phys. **C22**, 33 (1984).

Bu-95 V. Burkert and L. Elouadrhiri, Phys. Rev. Lett., **75**, 3614 (1995)

Ca-95 S. Capstick and B. Keister, Phys. Rev. **D51**, 3598 (1995).

Ca-96 F. Cardielli et al., Physics Letters **B371**, 7 (1996)

Da-97 R. Davidson and N. Mukhopadhyay, Phys. Rev. Lett. **79**, 4509 (1997)

Da-97a R. Davidson, private communication.

Ha-79 R. Haiden, DESY Report No. F21-79-03, unpublished, (1979)

Da-97 R. Davidson and N. C. Mukhopadhyay, private communication.

Kr-92 P. Kroll, M. Schurman, and W. Schweiger, Z. Phys. **A342**, 429 (1992)