CEBAF Program Advisory Committee Nine Proposal Cover Sheet

This proposal 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

Proposal Title

Measurement of $R = \sigma_L / \sigma_T$ in the Nucleon Resonance Region

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Experimental Hall: C **Days Requested for Approval:** 25 ✓

Hall B proposals only, list any experiments and days for concurrent running:

CEBAF Use Only

Receipt Date: PR 94-110

By:

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.

There is no new equipment required for this experiment.

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

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets

Power Supplies

Targets

Detectors

Electronics

Computer Hardware

Other

Other

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	Electrical Equipment	Radioactive/Hazardous Materials
___ beamline magnets _x_ analysis magnets _x_ target type: LH2 flow rate: 2 litres/sec capacity: 200 W	___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment none unique to this experiment	List any radioactive or hazadorous/ toxic materials planned for use: none
Pressure Vessels	**Flammable Gas or Liquids**	**Other Target Materials**
___ inside diameter ___ operating pressure ___ window material ___ window thickness none unique to this experiment	type: LH2 flow rate: ___ capacity: ___ **Drift Chambers** type: argon/ethane flow rate: ___ capacity: ___	___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) ___ Other (list below) none
Vacuum Vessels	**Radioactive Sources**	**Large Mech. Structure/System**
___ inside diameter ___ operating pressure ___ window material ___ window thickness none unique to this experiment	___ permanent installation ___ temporary use type: ___ strength: none	___ lifting devices ___ motion controllers ___ scaffolding or ___ elevated platforms none unique to this experim
Lasers	**Hazardous Materials**	**General:**
type: none wattage: ___ class: ___ Installation: ___ permanent ___ temporary Use: ___ calibration ___ alignment	___ cyanide plating materials ___ scintillation oil (from) ___ PCBs ___ methane ___ TMAE ___ TEA ___ photographic developers ___ other (list below) none	Experiment Class: _x_ Base Equipment x ___ Temp. Mod. to Base Equip. ___ Permanent Mod. to Base Equipment ___ Major New Apparatus Other: ___

BEAM REQUIREMENTS LIST

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

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	1200	100	none	All the proposed data uses	
2	2400	"	"	LH2 in 4cm cell	61.28g/cm2
3	4800	"	"		
4	6000	"	"		
5	2000	"	"		
6	3000	"	"		
7	4000	"	"		

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.

CEBAF PROPOSAL

Measurement of $R = \sigma_L/\sigma_T$ in the Nucleon Resonance Region

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MEASUREMENT OF $R = \sigma_L/\sigma_T$ IN THE NUCLEON RESONANCE REGION

Abstract

We propose to measure inclusive nucleon resonance electroproduction cross sections throughout the resonance region ($1 < W^2 < 4$ GeV^2) and spanning the four-momentum transfer range $0.75 < Q^2 < 7.5$ (GeV/c)^2. The cross sections will be used to perform Rosenbluth separations to extract the ratio $R = \sigma_L/\sigma_T$. The ratio R has been well measured in elastic electron-proton scattering up to $Q^2 = 8.83$ (GeV/c)^2 and in deep inelastic scattering up to greater than $Q^2 = 50$ (GeV/c)^2. However, it has not yet been measured accurately in the resonance region at moderate momentum transers. R is a fundamental quantity which has direct bearing on resonance form factor and spin dependent structure function measurements. It is essential for the development of reliable electron scattering models which will further our understanding of the underlying quark structure of the nucleon.

Additionally, the ratio R will be used to investigate Bloom-Gilman duality in conjunction with reliable global models of deep inelastic and resonance electroproduction data. In this duality may lie evidence for a common origin of both resonance electroproduction and deep inelastic scattering. QCD and pQCD predictions indicate that duality should hold for longitudinal as well as for transverse resonance cross sections. The proposed data will allow the first tests of Bloom-Gilman duality on longitudinal cross sections and more sensitive tests on transverse cross sections.

We request twenty-five days of beam time to measure inclusive nucleon resonance electroproduction cross sections spanning the entire resonance region and covering an intermediate to large momentum transfer region. Rosenbluth type separations will be performed to extract the ratio $R = \sigma_L/\sigma_T$ on the Δ $P_{33}(1232)$, $S_{11}(1535)$ and $F_{15}(1680)$ nucleon resonances to better than $\pm$ 0.01 up to $Q^2 = 7.5$ (GeV/c)^2. The experiment will utilize the existing equipment in Hall C with electron beam energies of 2.0, 3.0, and 4.0 GeV, and with 1.2, 2.4, 4.8 and 6.0 GeV. Electrons scattered from the 4 cm liquid hydrogen target will be detected in both the High Momentum Spectrometer (HMS) and the Short Orbit Spectrometer (SOS).

MOTIVATION

The description of hadrons and their excitations in terms of elementary quark and gluon constituents is one of the fundamental challenges in physics today. Quantum chromodynamics (QCD) is the theory of strong interactions that describes particles in terms of these elementary quantities. At small distance scales (or, correspondingly, high momentum transfers) where the quarks are close together, the color forces between the quarks are weak. The quarks are then said to be asymptotically free and perturbative methods may be applied to calculate quantities of physical interest. For deep inelastic scattering, i.e. scattering off pointlike quarks, it has been well established that perturbative QCD (pQCD) is a useful approximation for momentum transfers as low as a few $(\mathrm{GeV/c})^2$ and higher. This interaction is described by the coupling between a virtual photon and a single asymptotically free quark, followed by complicated hadronization processes. The small values of $R = \sigma_L/\sigma_T$, the ratio of the contributions to the cross section from longitudinally and transversely polarized virtual photons, measured in deep inelastic electron-proton scattering are typically interpreted to be a consequence of the spin-$\frac{1}{2}$ property of the charged partons involved in the quasi-free lepton-quark scattering process. Experimentally, L/T separations have been made to extract the ratio R from deep inelastic cross sections measured at momentum transfers as high as $Q^2 = 50$ $(\mathrm{GeV/c})^2$ [1, 2, 3, 4].

Electron scattering is well approximated by the exchange of a single virtual photon, due to the relatively small values of the electromagnetic coupling constant, and so theoretical calculations work well. This and the pointlike nature of the electron allow for clarity and precision in the interpretation of electron-nucleon scattering experiments; the reaction can be interpreted unambiguously in terms of the charge and current structure of the nucleon or nucleon resonance. Rosenbluth separations have been performed on precision electron-proton elastic cross sections out to $Q^2 = 8.83$ $(\mathrm{Gev/c})^2$ [5, 6, 7, 8, 9]. These separations allow the direct measurement of the proton elastic electric and magnetic form factors, $G_{Ep}(Q^2)$ and $G_{Mp}(Q^2)$. Measurements in this moderate Q^2 region are important because it is here that the virtual photon becomes sensitive to the internal quark structure of the proton. Measurements in this intermediate momentum transfer region provide valuable constraints on competing models which ultimately must describe the nucleon form factors to be considered fundamental theories.

In contrast to the elastic and to the deep inelastic, there exist very few separation measurements of the ratio $R = \sigma_L/\sigma_T$ in the nucleon resonance region at moderate or high momentum transfers. In a resonance excitation probed at moderate momentum transfer the partons are not free, and the arguments applied to the deep inelastic scaling data are not necessarily applicable. Large values of R could in principle be possible in the resonance region due to hard gluon exchanges between the quarks. The proposed experiment will measure R to approximately 10%, a substantial improvement over the presently available errors on R which are greater than 100% [10, 11, 12, 13, 14].

Figure 1 is a compilation of the proposed data and all existing electroproduction R data above $Q^2 = 0.8$ $(\mathrm{GeV/c})^2$ plotted as a function of Q^2. The SLAC data are from Reference [10]. The DESY data are from References [11, 12, 13, 14]. The available data span the entire resonance region in missing mass W^2 between $W^2 = 1$ GeV^2 and $W^2 = 4$ GeV^2. The error bars on the existing data are large and the data points scatter below and above R near zero, the expected result of scattering from asymptotically free quarks. An error weighted average of existing high four-momentum transfer ($Q^2 > 1\text{GeV/c}^2$) results for all Q^2, W^2 yields $R = .06 \pm .02$ [10]. However, the large error bars on the existing measurements prevent the conclusive exclusion of large values for R which the proposed higher precision data will allow. R could be large for specific resonances and is expected to decrease with increasing Q^2, but it is impossible given the imprecision of the existing data to determine any W^2 or Q^2 dependence of R. The proposed separations will be performed at missing mass values of $W^2 = 1.5$ GeV^2 (the missing mass of the $\Delta(1232)$ resonance), $W^2 = 2.3$ GeV^2 (the mass region of the $S_{11}(1535)$ resonance), and $W^2 = 2.9$ GeV^2 (the mass region of the $F_{15}(1680)$ resonance), for all proposed Q^2 values. The points on the plot for the proposed measurement assume the existing average value of $R = .06$ measured with 10% accuracy up to $Q^2 = 6.0$ (GeV/c)^2, with 15% accuracy at $Q^2 = 6.8$ (GeV/c)^2, and with 25% accuracy at $Q^2 = 7.5$ (GeV/c)^2.

Good measurements of R in the resonance region are necessary for a variety of fundamental measurements. The proposed measurements of the ratio will be useful in the extraction of resonance form factors and spin dependent structure functions from inclusive electron scattering experiments. Precision measurements of R will greatly aid efforts to develop reliable global descriptions of existing inclusive electroproduction data at moderate to high Q^2. These global models are necessary for electron-nucleon scattering model development and for accurate radiative correction calculations. An excellent global fit to existing SLAC deep inelastic data [1] has become available due, in part, to recent accurate measurements of R in deep inelastic scattering [3]. Efforts to extend this work to include the resonance region [10] have been hindered by the unavailability of separated data in the resonance region.

Over 20 years ago Bloom and Gilman observed the behavior of elastic scattering and of the electroproduction of nucleon resonances to be closely related to the behavior of deep inelastic electron-nucleon scattering [15, 16]. Precisely, the prominent resonances in inclusive electron-proton scattering do not disappear with increasing Q^2 relative to the background under them, but instead fall at roughly the same rate. Further, the smooth scaling limit seen at high Q^2 and W^2 for the structure function $F_2(\omega')$ where

$$\omega' = 1 + \frac{W^2}{Q^2} \tag{1}$$

is an accurate average for the resonance bumps seen at lower Q^2 and W^2, but at the same ω'. This observation is termed Bloom-Gilman duality. This relationship between resonance electroproduction and the scaling behavior observed in deep inelastic scattering points suggests a common origin for both phenomena.

A fundamental quark description for both properties of electroproduction may become possible by studying the Bloom-Gilman duality with new resonance electroproduction data and better measurements of R. Bloom and Gilman and subsequent authors [17, 18, 19, 20] have assumed constant values either of zero or around 0.2, consistent with that observed in deep inelastic scattering at moderate momentum transfer, for the ratio R for the resonances. The proposed data will test these assumptions and thus test the observed duality in greater detail.

Explanations from QCD and pQCD [21, 22, 23, 24] of the empirical connection between the scaling and resonance regimes indicate that both the σ_L and the σ_T structure functions should manifest Bloom-Gilman duality. The transverse contribution to the resonance cross section and to the non-resonant background is expected to have a $(\omega' - 1)^3$ dependence. Similarly, the longitudinal contribution to both the resonance cross section and to the non-resonant background is expected to have a $(\omega' - 1)^4$ dependence. In both cases, the resonance peaks move with changing Q^2 along a curve with the same shape as the scaling curve, and the signal-to-background ratio does not change with Q^2. These distinct manifestations of duality can be directly measured for the first time with the proposed measurements of R.

The Δ $P_{33}(1232)$ resonance is of particular interest in light of Bloom-Gilman duality. Although the behavior of the proton and of higher mass resonance form factors follows the leading order pQCD Q^{-4} prediction, the Δ resonance form factor is an anomaly and decreases significantly faster (at least for $Q^2 < 2$ (GeV/c)^2). To preserve Bloom-Gilman duality it has been suggested [23] that R is quite large for the Δ, i.e. that the cross section has a significant longitudinal component, allowing the observed scaling behavior of the structure function νW_2 for the Δ to be similar to the other resonances and to the proton. The precision high momentum transfer measurements of R proposed here will test this notion.

KINEMATICS

In this proposal we adopt a notation such that an electron with incident energy E scattering from the proton emerges with a final energy E' at a scattered angle θ. The exchanged virtual photon transfers a four-momentum q_μ to the target producing an undetected hadronic final state of mass W. The energy transfer is $\nu = E - E'$. Defining M to be the mass of the proton and neglecting the electron mass,

$$Q^2 = -q_\mu^2 = 4E_\circ E' \sin^2\left(\frac{\theta}{2}\right) \tag{2}$$

is the four-momentum transfer squared and

$$W^2 = M^2 + 2M\nu - Q^2 \tag{3}$$

is the square of the invariant mass of the hadronic final state. This assumes natural units wherein $\hbar = c = 1$.

If the scattering process is viewed as the Born approximation of production and absorption of a single virtual photon, the differential cross section for inelastic scattering is given by [25]:

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_m \left[W_2(\nu, Q^2) + 2W_1(\nu, Q^2)\tan^2\left(\frac{\theta}{2}\right)\right]. \tag{4}$$

Here, σ_m is the Mott cross section for scattering from a pointlike object:

$$\sigma_m = \frac{d\sigma}{d\Omega} = \frac{\alpha^2 \cos^2\theta/2}{4E_\circ^2 \sin^4\theta/2}. \tag{5}$$

The fine structure constant is $\alpha = e^2/4\pi = 1/137$ and $\Omega(\theta, \phi)$ is the laboratory solid angle of the scattered electron. The two structure functions $W_1(\nu, Q^2)$ and $W_2(\nu, Q^2)$ contain information concerning the electromagnetic structure of the nucleon resonance.

The almost twenty well-established nucleon resonances with masses below 2 GeV give rise to only three distinct enhancements in the measured inclusive electron scattering cross section. A typical inclusive spectrum is shown in Figure 2 for $Q^2 = 1$ (GeV/c)^2 with data from Reference [11] along with a parameterization of the data in terms of the resonant and non-resonant background components.

Of the three prominent enhancements, only the first is not a composite of overlapping resonant states. This is the $P_{33}(1232)$ state, or Δ resonance. There are two overlapping candidate states for the second enhancement: the $D_{13}(1520)$ and the $S_{11}(1535)$. Experiments at low Q^2 indicate that, as Q^2 increases, the cross section is dominated by the S_{11} resonance. The second enhancement will hereforward generally be referred to as the S_{11}. The third enhancement will be generally referred to as the $F_{15}(1680)$, or simply the F_{15}, since the $I = \frac{1}{2}$ resonant states are somewhat dominant at high Q^2 over the $I = \frac{3}{2}$ states in this mass region.

ROSENBLUTH METHOD

In order to study the behavior of R, the ratio of longitudinal to transverse photon absorption cross sections σ_L and σ_T, we intend to carry out a series of inclusive inelastic electron-proton scattering measurements, using the Rosenbluth separation technique. To this effect, we write the differential cross section measured by the detector system as:

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma[\sigma_T(W^2, Q^2) + \epsilon\sigma_L(W^2, Q^2)]. \tag{6}$$

This is known as the Rosenbluth formula. Here, Γ is the transverse virtual photon flux given by

$$\Gamma = \frac{\alpha\kappa E'}{4\pi^2 Q^2 E}\left(\frac{2}{1-\epsilon}\right) \tag{7}$$

and ϵ is the relative longitudinal virtual photon polarization parameter given by

$$\epsilon = \left[1 + 2(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]^{-1}. \tag{8}$$

Here,

$$\tau = \frac{\nu^2}{Q^2}. \tag{9}$$

These total virtual photon cross sections may be related to the structure functions $W_1(\nu, Q^2)$ and $W_2(\nu, Q^2)$ as follows:

$$\sigma_T = \frac{4\pi^2\alpha}{\kappa} W_1(\nu, Q^2) \tag{10}$$

and

$$\sigma_L = \frac{4\pi^2\alpha}{\kappa}\left[(1+\tau)W_2(\nu^2, Q^2) - W_1(\nu^2, Q^2)\right]. \tag{11}$$

The energy of an equivalent on-mass-shell (real) photon producing a final mass state W is κ. This is a model dependent quantity chosen here to be:

$$\kappa = (W^2 - M^2)/2M. \tag{12}$$

Dividing the measured differential cross section by Γ yields the reduced Rosenbluth cross section σ_R given by

$$\sigma_R = \frac{1}{\Gamma}\frac{d^2\sigma}{d\Omega dE'}. \tag{13}$$

The Rosenbluth equation for the reduced cross section is linear in ϵ. The slope of the line is σ_L and the vertical intercept is σ_T.

We propose to employ the Rosenbluth separation method using linear fits to reduced measured differential resonance cross sections to obtain the quantity $R = \sigma_L/\sigma_T$ throughout the resonance region. The proposed data points span a wide range in θ, i.e. a wide range in ϵ, at fixed values of (W^2, Q^2). The smallest ϵ range, $\Delta\epsilon$, considered in our proposal is 0.31 limited by the maximum beam energy of 6 GeV at the highest Q^2 points. The $\Delta\epsilon$ ranged from 0.31 to 0.67. The fixed W^2 values are the masses of the Δ, the S_{11}, and the F_{15}. The fixed Q^2 values are $0.75, 2.0, 3.0, 4.0, 5.0, 6.0, 6.8$, and 7.5 $(\mathrm{GeV/c})^2$.

PROPOSED EXPERIMENT

Figure 3 displays the kinematic regime covered by the proposed experiment. Bloom-Gilman duality has been observed to hold in this regime. The kinematic range where the proton elastic form factor and the form factors of the resonances above the Δ obey the leading order pQCD Q^{-4} behavior prediction is covered and the anomalous behavior of the Δ may be studied here. Unlike elastic or deep inelastic electroproduction, there have been no accurate L/T separations performed in this region.

Table 1 lists the kinematics and cross sections we propose to measure, as well as a break down of beam time requirements, for the $\Delta(1232)$ resonance. A minimum time of one half hour per kinematic setting and a maximum rate of 1000 Hz are used. The sum of the hours listed for all kinematic settings in Table 1 is larger than the requested beam time. It is important to note that many of these data will be obtained simultaneously with the two spectrometers placed at different angles and central momenta.

Table 2 indicates the kinematics at which data will be obtained simultaneously in the HMS and SOS spectrometers. The hours requested in Table 2 include measurements of the S_{11} and F_{15} resonances. These higher mass resonances have higher count rates and need approximately 10% of the running time of the Δ. Where possible, Rosenbluth separations will be performed on the three resonance enhancements at similar momentum transfers. However, the fixed (W^2, Q^2) necessary to the separation method are not within the kinematic limits of the spectrometers for the S_{11} and F_{15} masses at the high Q^2 values of 6.8 and 7.5 $(\mathrm{GeV/c})^2$. For these resonances, we propose to measure R to 10% at the maximum Q^2 values of 6.3 and 6.7 $(\mathrm{GeV/c})^2$.

The differential cross sections for inclusive electron scattering will be measured according to the following definition:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\Delta N}{\Delta\Omega\Delta E'}\frac{1}{Qnd}. \tag{14}$$

The counting rate per energy bin, ΔN, has been estimated for the purposes of this proposal from a recent global fit to all existing SLAC resonance region data [10]. This fit smoothly links with the global fit to SLAC deep inelastic scattering [1], providing a valuable tool for rate calculations as well as for testing electron nucleon scattering models and for input to radiative correction calculations. The fit is to data spanning the kinematic ranges $1.15 < W^2 < 4.0$ GeV^2 and $0.5 < Q^2 < 10.0$ $(\mathrm{GeV/c})^2$.

The scattered electron energy bins, $\Delta E'$, used to predict counting rates for this proposal were $\pm 10.0\%$ of the central spectrometer momentum for HMS data and $\pm 20.0\%$ of the central spectrometer momentum for SOS data. Solid angles, $\Delta\Omega$, of 7.0 msr and 9.0 msr were assumed for the HMS and SOS, respectively. Minimum central spectrometer momentum settings of 500 MeV and 700 MeV were used for the SOS and HMS, respectively.

All proposed measurments will use the Hall C 4 cm hydrogen target. In the above equation, n represents the density of hydrogen and d the target thickness.

The integrated number of incident electrons on target is the quantity Q. For the purposes of this proposal, we assumed an average current of 100 μamps.

The chosen beam energies in Tables 1 and 2 are either multiples of 1.0 GeV (2.0, 3.0 and 4.0 GeV) or 1.2 GeV (1.2, 2.4, 4.8 and 6.0 GeV). Thus, the actual beam energy need only be changed once between two proposed cycles of five pass beam.

UNCERTAINTIES

The run time requests were determined by the desired accuracy of the measurement of the longitudinal cross section component σ_L. The statistical error on σ_L is given by the equation

$$\Delta\sigma_L \approx \sqrt{2}\left(\frac{\Delta\sigma}{\sigma}\right)\left(\frac{\sigma}{\sigma_L}\right)\frac{1}{\Delta\epsilon} \tag{15}$$

which may be rewritten in terms of R to be

$$\frac{\Delta\sigma_L}{\sigma_L} \approx \sqrt{2}(\Delta\sigma/\sigma)\frac{1+}{R}\frac{1}{\Delta\epsilon}. \tag{16}$$

Table 1: Kinematics, cross sections, and beam time requirements for the proposed measurements at the fixed missing mass $W = 1232$ GeV of the Δ resonance. Rosenbluth separations will be performed for each of the eight fixed (W^2, Q^2) kinematics as indicated in the first column.

Q^2 $(\text{GeV/c})^2$	E (GeV)	E' (GeV)	θ (deg)	ϵ	Rate (Hz)	Time (Hours)	Spect
0.75	1.2	0.5	68	0.48	1000	0.5	SOS
	2.4	1.7	25	0.89	1000	0.5	HMS
2.0	2.0	0.6	80	0.31	124	0.5	SOS
	4.8	3.4	20	0.91	1000	0.5	HMS
3.0	2.4	0.5	104	0.14	17	2.0	SOS
	4.8	3.0	27	0.81	135	0.5	HMS
4.0	3.0	0.6	100	0.14	4.1	10	SOS
	6.0	3.5	25	0.82	56	0.7	HMS
5.0	4.0	1.0	68	0.31	3.5	30	HMS
	6.0	3.0	31	0.72	11	10	HMS
6.0	4.0	0.5	120	0.06	0.49	105	SOS
	6.0	2.5	37	0.61	2.8	20	HMS
6.8	4.8	0.9	80	0.19	0.46	160	HMS
	6.0	2.0	44	0.50	1.4	55	SOS
7.5	4.8	0.5	124	0.04	0.16	120	SOS
	6.0	1.6	52	0.40	0.68	30	SOS

This equation was used to determine the requisite statistical error, $\Delta\sigma/\sigma$, of the differential cross sections to be measured from the desired accuracy of the longitudinal component measurement. The required beam time for each kinematic setting was determined from the resultant $\Delta\sigma/\sigma$ using the counting rates per hour calculated from the SLAC global resonance cross section fit and given in Table 1. For the measurements at $Q^2 < 6.8$ $(\text{GeV/c})^2$, a value of 10% was used for $\Delta\sigma_L/\sigma_L$. A value of 15% was used for $Q^2 = 6.8$ $(\text{GeV/c})^2$ and a value of 25% was used for $Q^2 = 7.5$ $(\text{GeV/c})^2$. A value of $R = 0.06$ was assumed for all the tabulated calculations. The $\Delta\epsilon$ ranges are given in Table 1.

The statistical accuracy of the proposed differential cross section measurements (typically $\approx 1-2\%$) will be a significant improvement over the accuracy of existing data at moderate to high momentum transfers (typically $\approx 5-10\%$).

We plan to reduce normalization error by running the first two Q^2 points at 0.75 $(\text{GeV/c})^2$ and 2.0 $(\text{GeV/c})^2$ (which each take less than one half of an hour) with the spectrometers interchanged. For form factor extractions, there will be an uncertainty in the subtraction of the inelastic background. This is not, however, a necessary subtraction for the Bloom-Gilman studies.

Table 2: Kinematics, cross sections, and beam time requirements for all proposed measurements. Rosenbluth separations will be performed on the fixed W^2 masses of the Δ, S_{11}, and F_{15} resonances at similar momentum transfers. The Q^2 values which are tabulated are for the Δ unless indicated by an asterisk. The requested beam time is based on the values in boldface. The values in italics will be obtained simultaneously with those in boldface.

E GeV	Q^2 (GeV)/c^2	θ (deg)	ϵ	Rate (Hz)	Time (Hours)	Spect
1.2	0.75	68	0.48	3210	**0.5**	SOS
2.4	0.75	25	0.89	11252	*0.5*	HMS
	3.0	104	0.14	17	**3**	SOS
4.8	2.0	20	0.91	1719	*0.5*	HMS
	3.0	27	0.81	135	*0.5*	HMS
	6.3*	120	0.06	1.8	**50**	SOS
	6.7*	120	0.05	1.2	**65**	SOS
	6.8	80	0.19	0.46	*190*	HMS
	7.5	124	0.04	0.16	**145**	SOS
6.0	4.0	25	0.82	56	*0.8*	HMS
	5.0	31	0.72	11	*12*	HMS
	6.0	37	0.61	2.8	*24*	HMS
	6.3*	48	0.48	9.6	**10**	SOS
	6.7*	48	0.46	5.9	**13**	SOS
	6.8	44	0.50	1.4	**66**	SOS
	7.5	52	0.40	0.68	*36*	HMS
2.0	2.0	80	0.31	124	**0.5**	SOS
3.0	4.0	100	0.14	4.1	**12**	SOS
4.0	5.0	68	0.31	3.5	*35*	HMS
	6.0	120	0.06	0.49	**130**	SOS
				Total	**495**	

$\Delta(1232)$ FORM FACTOR

The kinematic range of this experiment allows for separated measurements to be made both in the low Q^2 region and in the intermediate Q^2 region where the observed behavior of the proton elastic form factor and the form factors of the resonances above the Δ obey the leading order pQCD Q^{-4} prediction. The Δ is of particular interest because the cross section decreases with increasing Q^2 significantly faster than the higher mass resonances which exhibit the Q^{-4} behavior predicted from pQCD [10, 18, 19, 20]. $\Delta(1232)$ transition form factors extracted from fits to individual SLAC cross section spectra [10] are plotted as a function of Q^2 in Figure 4.

Errors shown in Figure 4 include statistical and systematic errors, as well as estimated model errors for the nonresonant contribution. The diquark model fit of Kroll et al [26] and the heterotic model prediction of Stefanis and Bergman [27] are shown. The form factors are plotted normalized to the dipole form factor $F_D = \mu_p G_D$ where $\mu_p = 2.79$ nm is the proton anomalous magnetic moment. G_D is the dipole shape given by

$$G_D = (1 + \frac{Q^2}{0.71})^{-2}. \tag{17}$$

The results in Figure 4 were obtained using a value for R extracted from recent global fits to existing SLAC deep inelastic data. It has been predicted that the ratio R could be quite large for the Δ resonance [23, 24]. Values of R larger than those found in deep inelastic scattering at moderate momentum transfers would change the extracted high Q^2 values of the Δ form factor substantially.

BLOOM-GILMAN DUALITY

The original observations of Bloom and Gilman [15, 16] which showed the behavior of resonance electroproduction to be related in a striking way to that of deep inelastic scattering were of data from SLAC spanning the momentum transfer range $3 < Q^2 < 7$ $(\mathrm{GeV/c})^2$. The proposed data extend both below and above this range. Tests of duality at $Q^2 < 0.8$ [17] show 20% deviations from the Bloom and Gilman results but note that agreement increases with increasing Q^2.

The data proposed here will make possible not only the first test of duality on the longitudinal contribution to the cross section, but will also make possible considerably more precise observations of the original phenomena. Studies of duality have not yet been made which utilize the excellent global fits by Whitlow [1] to all existing deep inelastic SLAC data both for the structure function $F2$ and for R. The proposed measurements of R will allow greater precision in the extension of this global model to include all existing resonance region data. These global models will be used to calculate the Bloom-Gilman sum rule:

$$\frac{2M}{Q^2}\int_0^{\nu_m} \nu W_2(\nu, Q^2)d\nu = \int_1^{\omega'_2} F(\omega')d\omega'. \tag{18}$$

Table 3: A breakdown of the total time requested is tabulated below. We assume one hour for each angle change. We assume twenty-four hours for the overall beam energy change (major) and two hours for each change of energy between cycles of the five pass beam (minor). The requested data acquisition time is summarized in Table 2.

	Time Required (Hours)
Data acquisition	495
18 angle changes	18
Major beam energy change	24
5 minor beam energy changes	10
Checkout	48
Total	**595**

Confirmation of this sum rule would be a remarkable demonstration of the relationship between resonance physics and the physics of the deep inelastic regime.

CONCLUSIONS AND BEAM TIME REQUEST

We request a total of twenty-five days as shown in Table 3. This number is calculated assuming that each angle change will take one hour and that the major beam energy change from 5.0 GeV maximum energy to 6.0 GeV maximum energy will take twenty-four hours. The minor beam energy changes within the five pass accelerator cycle (i.e. from 3.0 to 2.0 GeV, etc.) are assumed to take two hours each. We request a hardware and data acquisition checkout time of two days.

In this time we propose to measure $R = \sigma_L/\sigma_T$ on the $S_{11}(1535)$ and $F_{15}(1680)$ nucleon resonances with 10% accuracy up to $Q^2 = 6.7$ (GeV/c)^2, and on the Δ $P_{33}(1232)$ resonance with 10% accuracy up to $Q^2 = 6.0$ (GeV/c)^2, 15% accuracy at $Q^2 = 6.8$ (GeV/c)^2, and 25% accuracy at $Q^2 = 7.5$ (GeV/c)^2. These data will be a significant improvement on the presently available measurements, allowing for better nucleon resonance model development, resonance form factor extraction, and improved radiative correction calculations. The new data will be used for precision studies of Bloom-Gilman duality and for the first test of this duality on the longitudinal cross section.

REFERENCES

1. L.W. Whitlow et al., Phys. Lett. B250, 193 (1990)

2. A. Bodek et al., Phys. Rev. D20, 1471 (1979)

3. S. Dasu et al., Phys. Rev. Lett. 61, 1061 (1988)

4. L.H. Tao, Ph.D. Thesis, The American University (1994)

5. R.C. Walker et al., Phys. Lett. B224, 353 (1989)
6. R.C. Walker et al., Phys. Lett. B240, 522 (1990)
7. P.E. Bosted et al., Phys. Rev. C42, 38 (1990)
8. L. Andivahis et al., submitted to Phys. Rev. D
9. L. Andivahis, Ph.D. Thesis, The American University (1993)
10. C.E. Keppel, Ph.D. Thesis, The American University (1994)
11. F.W. Brasse et al., Nucl. Phys. B110, 413 (1976)
12. J. Drees et al., Z. Phy. C7, 183 (1981)
13. J.C. Alder et al., Nucl. Phys. B48 (1972)
14. B. Gerhardt et al., Z. Phy. C7, 11 (1981)
15. E.D. Bloom and F.J. Gilman, Phys. Rev. D4, 2901 (1970)
16. E.D. Bloom and F.J. Gilman, Phys. Rev. Lett. 25, 1140 (1970)
17. J. Moritz, Nucl. Phys. B41, 336 (1972)
18. P. Stoler, Phys. Reports 226, 103 (1993)
19. P. Stoler, Phys. Rev. Lett. 66, 1003 (1991)
20. P. Stoler, Phys. Rev. D44, 73 (1991)
21. C.E. Carlson, Phys. Rev. D34, 2704 (1986)
22. G.R. Farrar and D.R. Jackson, Phys. Rev. Lett. 35, 21 (1975)
23. C.E. Carlson and N.C. Mukhopadhyay, Phys. Rev. D41, 2343 (1990)
24. C.E. Carlson and N.C. Mukhopadhyay, Phys. Rev. D47, 1737 (1993)
25. S.D. Drell and J.D. Walecka, Ann. Phys. 28, 18 (1964)
26. P. Kroll, M. Schurmann, W. Schweiger, Z. Phys. A342, 429 (1992)
27. N. Stefanis and M. Bergmann, Phys. Lett. B304, 24 (1993)

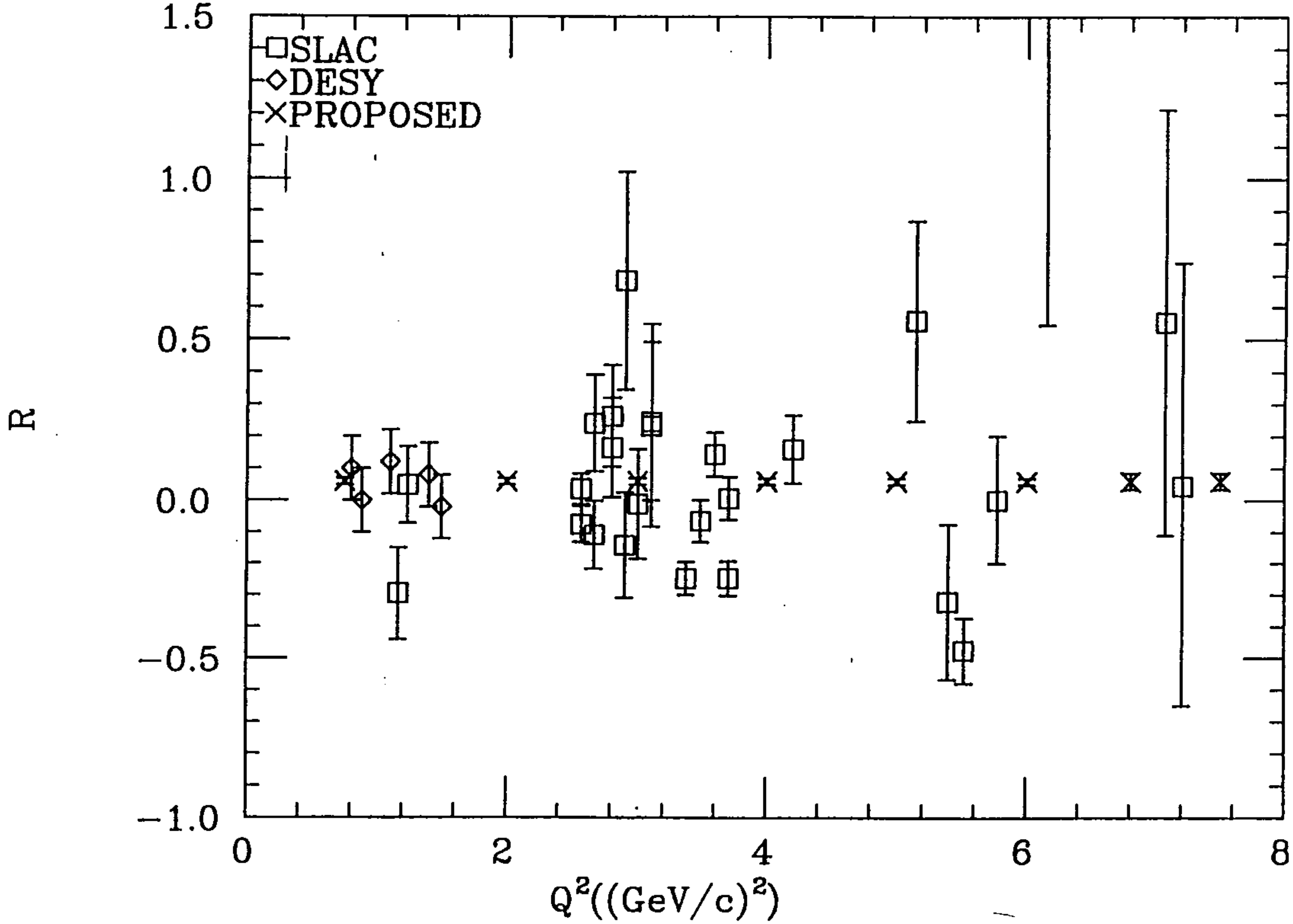

Figure 1: The quantity $R = \sigma_L/\sigma_T$ is plotted as a function of the momentum transfer Q^2 in $(\text{GeV/c})^2$ for all existing data as compared to the proposed data. The errors shown are statistical only.

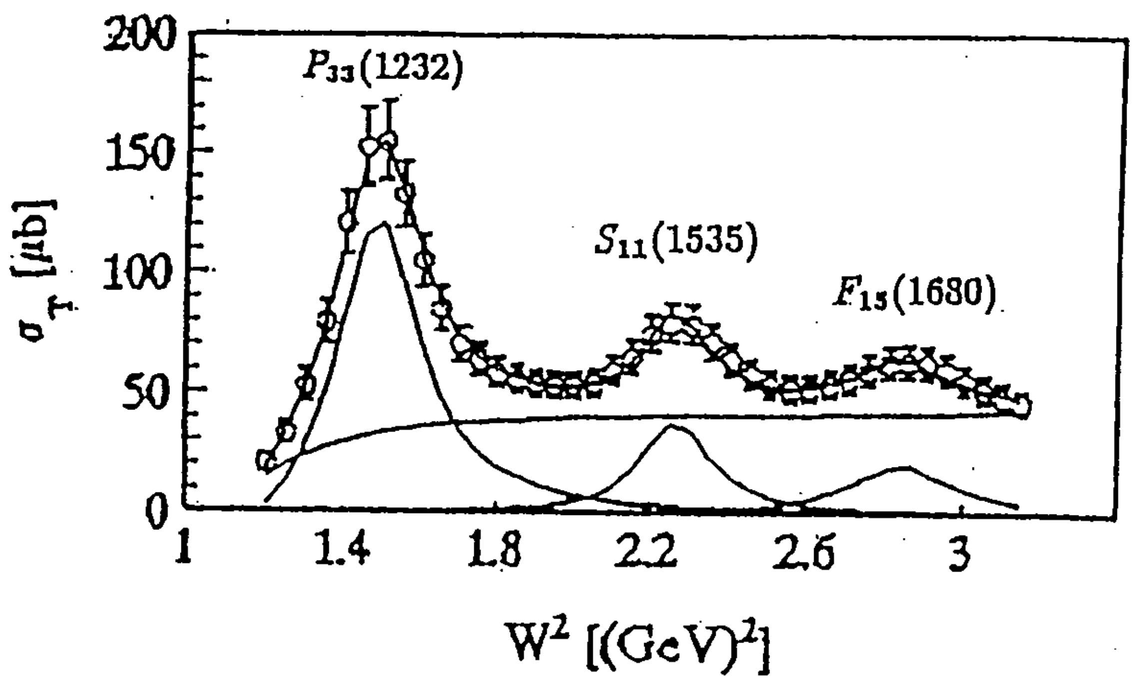

Figure 2: A typical inclusive nucleon resonance electroproduction cross section spectrum covering the entire resonance region ($1 < W^2 < 4$ GeV^2) is shown for $Q^2 = 1$ (GeV/c)^2. The three prominent enhancements are labelled as described in the text.

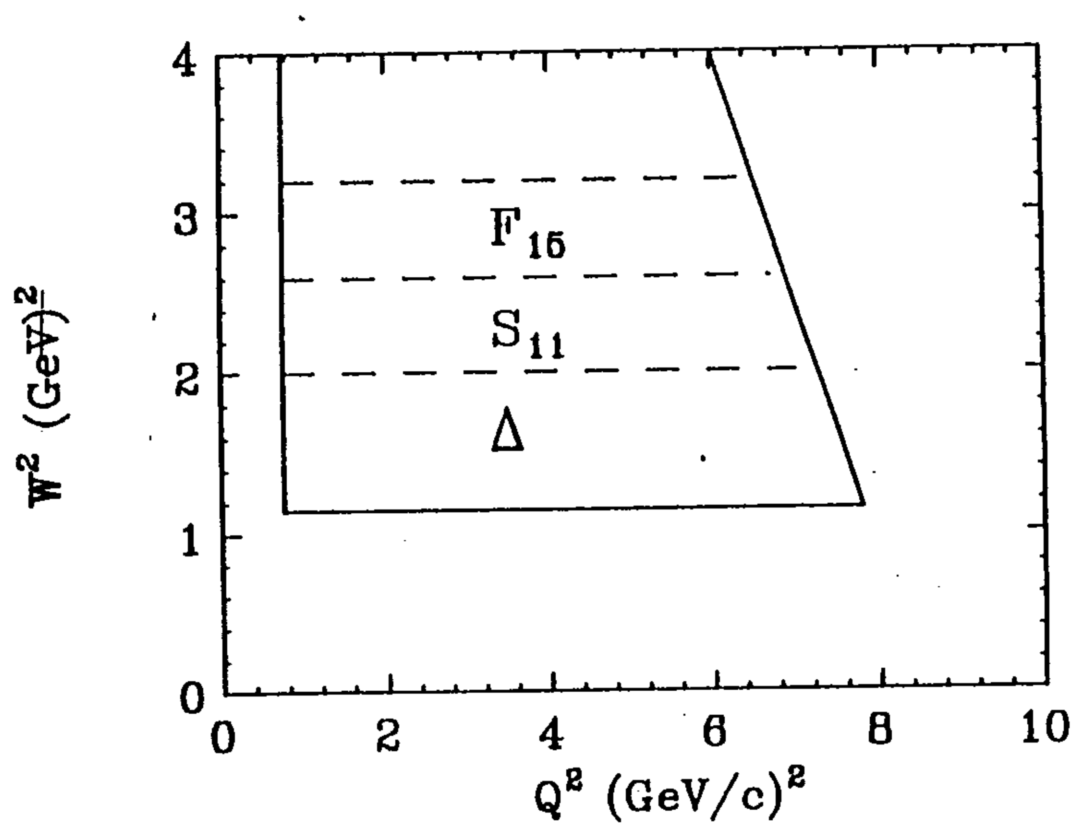

Figure 3: The kinematic region covered by the proposed experiment is plotted in both W^2 and Q^2. The mass ranges of the prominent resonance enhancements to the inclusive cross section are indicated.

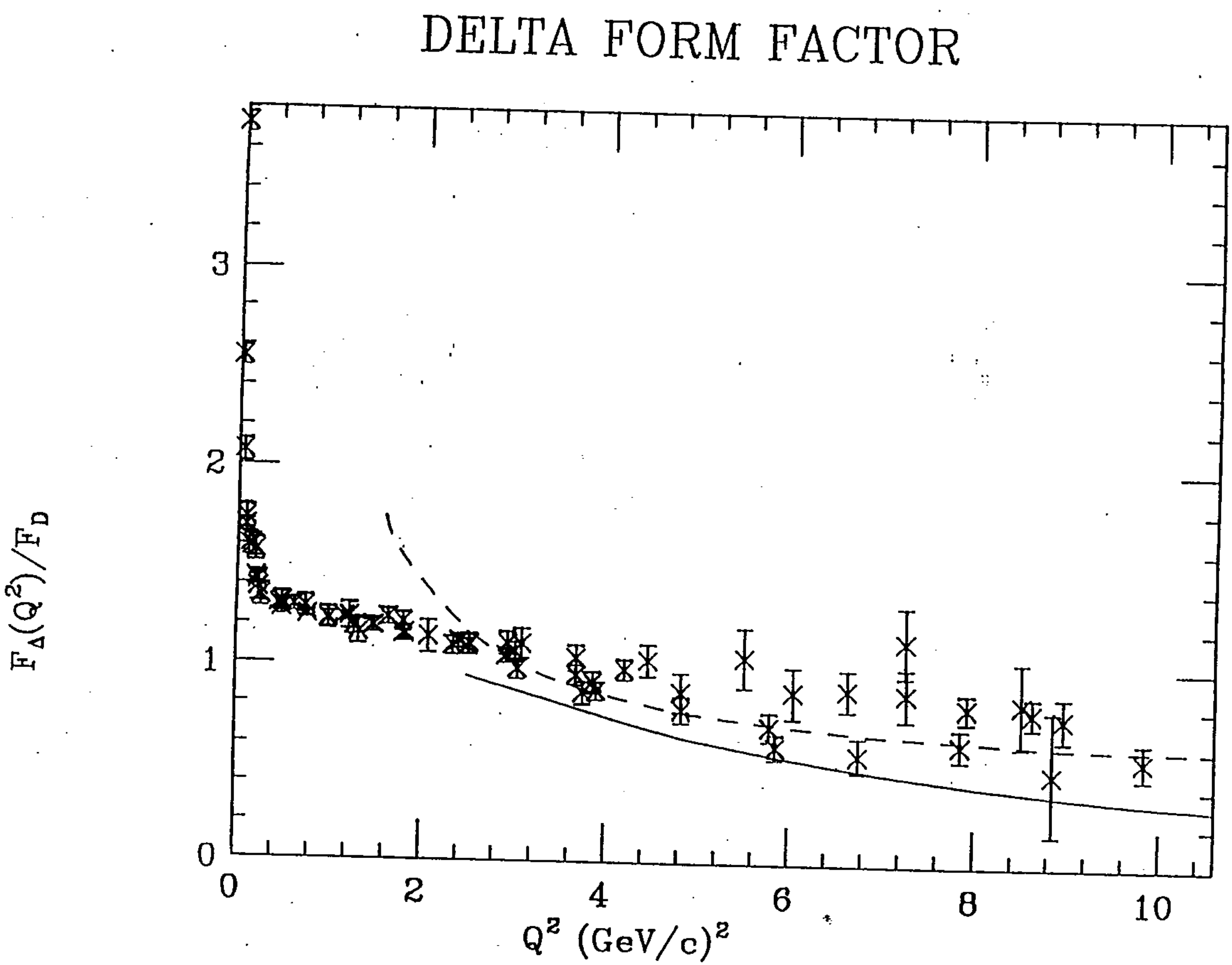

Figure 4: $\Delta(1232)$ transition form factors extracted from fits to individual SLAC cross section spectra are plotted for the central Q^2 points of the spectra. The errors shown include statistical and systematic errors, as well as estimated model errors for the non-resonant contribution. The dashed curve is the model from Stefanis and Bergman. The solid curve is the model from Kroll.