JLab Program Advisory Committee Eleven Proposal Cover Sheet

This document must be received by close of business on Wednesday, December 18, 1996 at:

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

(Choose one)

☐ **New Proposal Title:**

☒ **Update Experiment Number:** 94-110: Measurement of R= σ_L/σ_T in the Nucleon Resonance Region

☐ **Letter-of-Intent Title:**

Contact Person

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Experimental Hall: __C__   **Days Requested for Approval:** __27__

BEAM REQUIREMENTS LIST

JLab Proposal No.: _____E94-110_____   Date: __12/18/96__

Hall: __C__   Anticipated Run Date: _____   PAC Approved Days: _____

Spokesperson: _Cynthia Keppel_____   Hall Liaison: _R. Carlini_____
Phone: _(757) 727-5823_____
E-mail: keppel@jlab.org_____

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)
		PHASE I		all of the proposed data uses the		
1	1.045	80	none	standard Hall C	4cm hydrogen	target. 0.5
2	2.045	"	"			4
3	4.045	"	"			28
4	5.045	"	"			7.5
5	1.645	"	"			4
6	2.445	"	"			3.5
7	3.245	"	"			16.5
8	2.745	"	"			3.5
9	3.645	"	"			71
		PHASE II				
1	4.845	80	none			230
2	6.045	"	"			66
3	4.045	"	"			100

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 REQUIREMENTS LIST

CEBAF Proposal No.: _____94–110_____
(For CEBAF User Liaison Office use only.)

Date: ___12/18/96_____

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 Experiment: ___E94-110___   Date: ___12/18/96___

Check all items for which there is an anticipated need—do not check items that are part of the CEBAF standard experiment (HRSE, HRSH, CLAS, HMS, SOS in standard configurations).

Cryogenics	Electrical Equipment	Radioactive/Hazardous Materials
____ beamline magnets _x_ analysis magnets _x_ target _x_ drift chambers ____ other	____ 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 ____ inside diameter ____ operating pressure ____ window material ____ window thickness none unique to this experiment	**Flammable Gas or Liquids** (incl. target) type: ___LH2___ flow rate: _____ capacity: _____ standard 4cm hydrogen target	**Other Target Materials** ___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) _x_ Other (list below) ___aluminum "empty"___ ___target___
Vacuum Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness none unique to this experiment	**Radioactive Sources** ____ permanent installation ____ temporary use type: _____ strength: _____ none	**Large Mech. Structure/System** ____ lifting devices ____ motion controllers ____ scaffolding or elevated platforms ____ other none unique to this experiment
Lasers type: ___none___ 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) ___none___	**Notes:** ___This experiment uses___ ___standard Hall C equipment___ ___and materials.___

Update to TJNAF Experiment 94-110

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

Submitted by

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Experiment 94-110 Update
Measurement Of $R = \sigma_L/\sigma_T$
In The Nucleon Resonance Region

December 18, 1996

We propose to perform a global survey of longitudinal strength throughout the nucleon resonance region ($1 < W^2 < 4$ GeV^2) and spanning the four-momentum transfer range $0.75 < Q^2 < 7.5$ (GeV/c)^2. Inclusive nucleon resonance electroproduction cross sections will be used to perform Rosenbluth separations to extract the ratio $R = \sigma_L/\sigma_T$. We intend to measure R with an order of magnitude less uncertainty (≈ 0.05), than the current errors on R which have uncertainties greater than 0.5. The 1994 Program Advisory Committee (PAC) 9 conditionally approved this experiment, stating that "Clearly, the L/T ratio on the proton is a fundamental quantity that should be measured with the best possible accuracy." Concern was expressed, however, regarding the achievability of the proposed systematic uncertainties.

In this update, we report on the currently achievable precision in Hall C and apply this to our proposed measurements. Additionally, we introduce a run plan for using a maximum beam energy of 5 GeV. With this energy, it is possible to span the four-momentum transfer range $0.75 < Q^2 < 4.9$ (GeV/c)^2. This follows the PAC's suggestion that "a subset of the proposed kinematics should be selected in order to first demonstrate the claimed accuracy." The PAC also suggested making a kinematic connection with the high energy $R(Q^2)$ SLAC data, which is included in the proposed kinematics.

Review of Motivation and Goals

We present here a brief overview of the physics motivation and goals of this proposal. We refer to the original proposal (attached) for a more detailed discussion.

The ratio of longitudinal to transverse electron scattering off the proton is a fundamental quantity. 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 understanding 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 $Q^2 = 8.83$ (GeV/c)^2 [1, 2, 3, 4, 5]. These separations allow the direct measurement of the proton 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.

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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.

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 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. 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 $(\text{GeV/c})^2$ and higher. This interaction is described by the coupling between a virtual photon and a single asymptotically free quark, followed by a complicated hadronization processes. Measurements have been made to extract the ratio R from deep inelastic cross sections at momentum transfers as high as $Q^2 \approx 50$ $(\text{GeV/c})^2$ [6, 7, 8, 9].

In contrast to both the elastic and the deep inelastic, there exist few separation measurements of the ratio R in the 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. Experiment 94-110 proposes to measure R to approximately 0.05, a substantial improvement over the presently available errors on R which are greater than 0.5 [11, 12, 13, 14, 15].

Figure 1 shows the world data on R in the resonance region. The error bars are typically $\geq 500\%$. These data are averaged over $1 < W^2 < 4$ GeV^2. The proposed points for the Δ $P_{33}(1232)$ are plotted at a constant value of $R = 0.06$, a weighted average of the existing data, for comparison. They are labelled phase 1 and phase 2 for reasons to be elucidated. Similar error bars will be obtained for the higher mass resonances. Statistical errors only are plotted. The systematic uncertainty in R is expected to be less than 0.05 and will be discussed in the next section.

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. The proposed measurements will be useful in the extraction of resonance form factors and spin-dependent structure functions from inclusive electron scattering experiments.

Additionally, the ratio R will be used to investigate an observed scaling relationship between resonance electroproduction and deep inelastic scattering, termed Bloom-Gilman duality. This duality suggests a common origin of both phenomena and studies of duality with new resonance data and better measurements of R may enable a fundamental quark description for both properties of electroproduction. Explanations from QCD and pQCD [16, 17, 18, 19] of the empirical connection between the scaling and resonance regimes indicate that both the transverse and the longitudinal contributions to the resonance cross section should manifest Bloom-Gilman duality. These models of duality may be tested 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
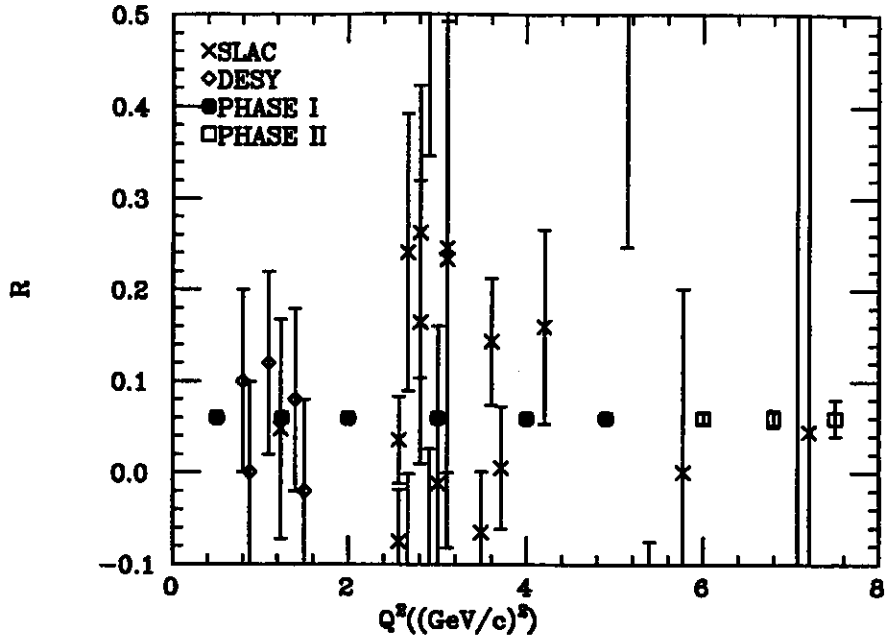
2

Figure 1: The world data on $R = \sigma_L/\sigma_T$ in the nucleon resonance region plotted as a function of Q^2 in $(\text{GeV/c})^2$ averaged between $1 \leq W^2 \leq 4$ $(\text{GeV/c})^2$. The proposed points for the Δ $P_{33}(1232)$ only are plotted at a constant value of $R = 0.06$ for comparison. Proposed phase 1 points are solid circles and phase 2 points are open squares. Errors shown are statistical only.

the leading order pQCD Q^{-4} prediction, the Δ resonance form factor is an anomaly and decreases significantly faster (at least for $Q^2 < 2$ $(\text{GeV/c})^2$). To preserve Bloom-Gilman duality it has been suggested [18] 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.

Systematic Uncertainties

The state of the art in precision longitudinal/transverse separation measurements has been obtained by experiment E140X at SLAC, a measurement of R in deep inelastic scattering. Table 1 displays the achieved point-to-point systematic uncertainties for experiment E140X.

Table 2 displays the effect (ΔR) of point-to-point systematic uncertainties on R, measured at the delta resonance and at the third inclusive resonance enhancement (labelled F_{15}), with uncertainties which we anticipate obtainable in Hall C at TJNAF. The values ΔR shown were calculated for $Q^2 = 7.5$ $(\text{GeV/c})^2$ using cross sections from a global fit to all existing SLAC inclusive resonance electroproduction data. At the bottom of Table 2 are values for ΔR if the electron beam energy can be measured at the $\Delta E \approx 10^{-4}$ level. The largest systematic uncertainties are from the incident and scattered electron energies, causing a $\Delta R \approx 0.05$ in the worst case.

The electron beam position and angle on target are measured with beam position

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Table 1: Point-to-point systematic uncertainties from experiment E140X at SLAC.

		$\Delta\sigma$ (%)	ΔR
Beam Steering	$0.003°$	0.1	0.005
Beam Energy	$1 \cdot 10^{-3}$	0.3	0.014
Acceptance vs θ	0.1%	0.1	0.005
Acceptance vs p	0.1%	0.1	0.005
Spectromet r Angle	$0.002°$	0.1	0.005
Beam Charge	$3 \cdot 10^{-3}$	0.3	0.014
Target Density	0.2%	0.2	0.009
Scattered Electron Energy	0.05%	0.1	0.005
Detector Efficiency	0.1%	0.1	0.005
e^+/e^- background	0.1%	0.1	0.005
Radiative corrections	1%	1.0	0.030
	Total	1.1	0.039

Table 2: Anticipated point-to-point relative systematic uncertainties at the highest Q^2 values for the $P_{33}(\Delta)$ and F_{15} resonances.

		ΔR	ΔR
		$P_{33}(\Delta)$	F_{15}
Beam Steering	$0.003°$	0.005	0.005
Beam Energy	$1 \cdot 10^{-3} \to 1 \cdot 10^{-4}$	0.030	0.005
Acceptance	0.2%	0.010	0.010
Scattering Angle	$0.01°$ (≈ 0.2 mr)	0.020	0.005
Beam Charge	$1 \cdot 10^{-3}$ relative	0.005	0.005
Target Density	$< 0.2\%$	0.009	0.009
Scattered Electron Energy	0.04%	0.030	0.010
Detector Efficiency	0.1%	0.005	0.005
Deadtime Corrections	0.1%	0.005	0.005
	Total	0.050	0.021
	Total for $\Delta E \approx 10^{-4}$	0.028	0.018

monitors in the Hall C beam line. We plan to use the Hall C fast raster with a beam spot size at target of ± 1 mm. The vertical component of this deviation will appear as an apparent momentum offset of maximum 0.08% in the HMS and 0.04% in the SOS, and can to first order accurately be corrected with the recorded beam position as calculated from the fast raster field. The disadvantage of using such a small raster size is a potential change in target density which can, however, be calibrated by recording the electron singles in the spectrometer during a current calibration (this involves a current scan). The phase of the fast raster signals, as recorded in the electronics, with respect to the actual field setting can be calibrated by performing an elastic measurement and plotting the invariant mass versus the raster information (the deflections will cause offsets in W^2 due to apparent changes in spectrometer momenta and angles). This has routinely been done during the last year of running, and the phase has been found to be close to zero degrees. To monitor the absolute beam position on an event-by-event basis we use the fast raster signals to determine the fast component of beam motion induced by the fast raster and beam position monitors (BPMs) to determine the slow component of beam motion (up to 1 kHz bandwidth). The BPMs get calibrated by inducing a deflection of the beam by a magnet far upstream, and verifying BPM recorded motion with the motion derived from the Superharps. This can be done at various currents to calibrate the current dependence of the readout. The BPM signals are recorded in both the data acquisition stream and on a monitoring screen to minimize drifts. Note that it is planned to install SEE (Switched Electrode Electronics) beam position monitors before September 1997. The latter BPMs provide a ± 100 μm accuracy for currents between 0.4 and 2000 μA and therefore require less calibration. These BPMs will also be used for fast feedback systems for both beam position and beam energy in Hall C.

The beam energy is currently measured in Hall C at the $\Delta E \approx 10^{-3}$ level using a so-called Arc Measurement which entails a combination of beam position measurements with three Superharps located at the entrance, the middle, and the exit of the Hall C arc. The absolute value of these measurements has been verified to be precise up to $1 \cdot 10^{-3}$ against the following calibration measurements:

- A differential recoil method using a BeO target at 1-pass beam energy.

- A measurement of the position of the first minimum of the ^{12}C elastic form factor at 1-pass and 2-pass beam energies.

- A set of ^{1}H(e,e') and ^{1}H(e,e'p) measurements taken during the data taking cycle in 1996, at various beam energies.

All of these measurements agree at the 10^{-3} level with each other and with the mentioned Arc methods, with the exception of one spurious Arc measurement in December 1995. It is to be noted that elastic data will be obtained at all momentum transfers of this proposal.

Efforts are also underway to utilize the well-known Compton Scattering process as a tool to measure the centroid energy of the electron beam at the $\Delta E \approx 10^{-4}$ level. This requires scattering a far-infrared laser off the electron beam, and measuring the energy of the scattered γ-rays very precisely using a solid-state detector. With the aid of an NSF CAREER grant to the spokesperson, a laser has been purchased and a laboratory has been established at the nearby NASA Langley Research Center for precision beam

energy instrumentation development. A study of photon backgrounds in the Hall C arc has been performed by members of the E94-110 collaboration which indicates that the general room background in the area where we want to install the solid-state detector is less than 10 kHz for stable beam conditions and high current (for photon energies above 100 keV). The room background is not expected to pose any problem for this energy measurement method.

Relative beam energy corrections are possible by correcting the variation in beam energy using the BPMs in the Hall C Arc. This information is recorded every second in the Hall C data stream. In the center of the Hall C Arc the dispersion is 2.2 cm/%, while the BPMs easily give better beam position information than 0.2 mm for fixed beam conditions. Variations in beam energy of order 0.05% (due to RF instabilities in the accelerator cavities) have been witnessed and successfully been unfolded from the data, as verified by missing mass reconstruction.

Monte Carlo models of both the HMS and SOS spectrometers exist which reproduce elastic hydrogen data obtained in Hall C to better than 2% for HMS (within a momentum range of ±8%), and presently to better than 5% for SOS within a limited momentum range (-5 to +15%). We are still working on optimizing the optics models for both spectrometers.

According to present Hall C survey results, the HMS scattering angle is reproducible to within $0.01°$ and the SOS to within $0.03°$. This angle uncertainty is caused by a two-fold effect: 1) the motion of the magnets on the respective carriages, which is for HMS less than 0.5 mm and for SOS less than 2 mm with respect to the optical axes, and 2) the discrepancy between the pivot point and the spectrometer rotation point. For SOS the first uncertainty is dominant. However, note that the SOS magnets always *reproduce* to better than 1.0 mm. For HMS the rotation point is about 2 mm upstream and 0.3 mm towards the SOS side with respect to the pivot point. Note that the optical axis for both HMS and SOS has been established by using the Cotton-Mouton effect (an optical technique to establish the optical axis with respect to mechanical references). These survey results inflict an absolute uncertainty of less than 0.5 mr in the scattering angle as determined with HMS. We are still investigating the absolute uncertainty in the scattering angle of SOS, but it is currently believed to be better than 2 mr.

The beam charge in Hall C for currents above 10 μA is measured with beam charge monitors (BCMs). An absolute calibration of these BCMs against an Unser monitor would be performed at each beam energy change, yielding in the worst case an uncorrelated ±0.2 μA error (σ) for an 80 μA beam (limited by the noise in the absolute Unser monitor measurement). Presently, short term temperature drifts (few $\cdot 10^{-3}$) are visible as the cavity temperature regulation cycles between $110 \pm 1°$F. This is almost certainly due to the tuning plunger being out of phase with the cavity body in their thermal contraction cycles. The temperature regulation circuit will be upgraded to reduce temperature cycling by an order of magnitude. Studies of these temperature drifts are still in process, but they are not expected to prevent a relative charge monitoring down to the 0.1% level [10].

Initial target density measurements have been performed during the 1996 calendar year. Effects on the order of $\approx 3\%$ have been witnessed for a ±1 mm raster size and a current of 80 μA. It is expected that these effects will be reduced by using a faster fan speed. More studies are planned for 1997 where we will vary the fan speed and the

intrinsic beam spot size to verify our understanding of these target density changes. Also the reproducibility of these witnessed target density changes as a function of incident beam current and fast raster size is still to be verified. The latter would constitute sufficient conditions for the proposed measurements.

Computer deadtimes in Hall C have been measured by analyzing data obtained at constant running conditions, but varying trigger prescale values. From such an analysis, the uncertainty in deadtime is projected to cause a less than 0.1% systematic uncertainty on the proposed measurements.

If both spectrometers are used, some data will be obtained at matching kinematics for a check of the relative normalization. For the proposed 5 GeV maximum energy runplan below, all data in the relatively more sensitive Δ region (due to the faster dropoff as a function of momentum transfer) will be obtained in the HMS spectrometer.

What Is Currently Obtainable?

During the PAC 9 meeting, the question was raised what portion of this proposal was possible with a 4 GeV beam energy. In the summer of 1996, a single pass beam energy of 1 GeV was obtained at TJNAF, allowing for the possibility of 5 GeV, 5 pass beam in the near future. Here we will discuss what portion of our original proposal is possible assuming a maximum beam energy of 5 GeV and uncertainties as discussed above. We have modified the proposal to run in two phases, one with a maximum beam energy of 5 GeV and another utilizing the 6 GeV maximum beam energy to complete the higher Q^2 kinematics. Our original proposal is attached for reference.

Figure 2 depicts the kinematics coverage of the full 6 GeV proposal, as well as kinematics achievable at 5 GeV. It is possible to measure R out to $Q^2 \approx 5$ $(GeV/c)^2$ using a maximum allowable beam energy of 5 GeV with the same precision as the measurements originally proposed for 6 GeV. The data overlap both the elastic and the deep inelastic regimes.

Table 3 depicts lists the kinematics and cross sections we propose to measure in phase 1, as well as a breakdown of beam time requirements. A minimum time of one half hour per kinematic setting and a maximum rate of 1000 Hz are used. A beam current of 80 μA was used. The $W^2 = 1.52$ $(GeV/c)^2$ Δ resonance data will all be obtained in the HMS spectrometer to reduce systematic uncertainties, as discussed above. The higher mass resonances have higher count rates and require approximately $\leq 50\%$ of the running time of the $\Delta(1232)$ for kinematics other than those noted in the table. An additional 9 hours is required, then, to obtain data for the S_{11} and F_{15} resonances between $0.5 \leq Q^2 \leq 3.0$ using the HMS spectrometer.

Where possible, Rosenbluth separations will be performed on the three resonance enhancements at similar momentum transfers. However, the fixed (W, 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 $Q^2 = 4.9$ $(GeV/c)^2$. For these resonances, we propose to measure R with $\Delta R \approx 0.04$ around $Q^2 = 4$ $(GeV/c)^2$, as tabulated. The SOS spectrometer will be used to obtain the highest Q^2 measurements on the higher mass kinematics (labelled in the table as $W^2 = 2.36, 2.89$ and 3.4 $(GeV/c)^2$. This SOS data can be obtained in a simultaneous single arm mode with the HMS data and, so, adds no time to the beam time request.

Table 3: Phase 1 kinematics

| HMS						
Q^2	E	E'	Θ	ϵ	rate	time
$(\text{GeV}/c)^2$	GeV	GeV/c^2	deg		Hz	hours
$W^2 = 1.52\ (\text{GeV}/c)^2$						
4.90	5.045	2.098	39.78	0.580	18	5
	4.045	1.098	63.35	0.321	4	25
	3.645	0.698	87.85	0.163	2	71
4.00	5.045	2.578	32.20	0.704	90	1
	4.045	1.578	46.63	0.516	25	3
	3.245	0.778	78.01	0.232	5	15
3.00	5.045	3.111	25.25	0.816	644	0.5
	3.245	1.311	49.66	0.510	66	1
	2.745	0.811	70.97	0.304	20	3
2.00	5.045	3.644	18.99	0.900	1K	0.5
	2.745	1.344	43.21	0.617	425	0.5
	2.045	0.644	76.09	0.292	70	1
1.25	5.045	4.043	14.22	0.947	1K	0.5
	2.445	1.443	34.62	0.741	1K	0.5
	1.645	0.643	65.83	0.398	420	0.5
0.50	3.245	2.643	13.87	0.951	1K	0.5
	1.645	1.043	31.32	0.787	1K	0.5
	1.045	0.443	62.61	0.439	1K	0.5
$0.5 \leq Q^2 \leq 3.0$	$W^2 > \Delta$					9
TOTAL						**138**
SOS						
$\text{W}^2 = 2.36\ (\text{GeV}/c)^2$						
4.40	5.045	1.912	39.47	0.546	67	2
	4.045	0.912	66.20	0.267	15	8
	3.645	0.512	100.33	0.097	3	40
$\text{W}^2 = 2.89\ (\text{GeV}/c)^2$						
4.00	5.045	1.843	38.29	0.538	122	1
	4.045	0.843	65.60	0.253	19	4
	3.645	0.443	103.88	0.079	5	15
$\text{W}^2 = 3.40\ (\text{GeV}/c)^2$						
3.60	5.045	1.784	36.87	0.532	177	0.5
	4.045	0.784	64.38	0.242	25	3
	3.645	0.384	106.64	0.066	5	14
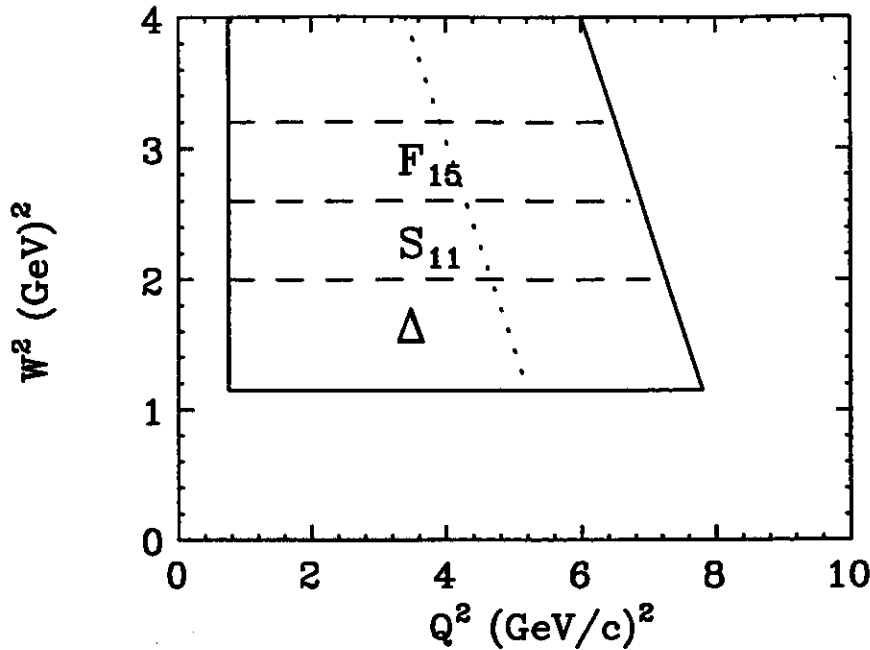
Figure 2: Kinematics coverage for both phases of the proposed experiment. Phase 1, indicated by the dotted line, will acquire data for L/T separations spanning the entire resonance region out to $Q^2 \approx 5$ (GeV/c)^2. Phase 2 completes the proposed measurements out to $Q^2 \approx 7.5$ (GeV/c)^2.

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

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

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 [11]. This fit smoothly links with the global fit to SLAC deep inelastic scattering [6], 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 $0.5 < Q^2 < 10.0$ (GeV/c)^2.

The scattered electron energy bins, $\Delta E'$, used to predict counting rates for this proposal were $\pm 8.0\%$ of the central spectrometer momentum of the HMS. A solid angle, $\Delta\Omega$, of 6.5 msr was assumed for the HMS. A minimum central spectrometer momentum setting of 380 MeV/c was used. All proposed measurements 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 update, we assumed an average current of 80 μA. The chosen beam energies in the table are multiples of 1.0 GeV (1.0, 2.0, 4.0, 5.0), 800 MeV (1.6, 2.4, 3.2 GeV), and 900 MeV (2.7, 3.6 GeV). These represent the 5 pass 5 GeV tune, the standard tune, and a special tune with 900 MeV base energy.

The run time requests were determined by the desired accuracy of the measurement

Table 4: Beam time request for phase 1 (5 GeV maximum beam energy) and for phase 2 (6 GeV maximum beam energy) of the proposed experiment.

	Phase 1 Time (hours)	Phase 2 Time (hours)
Data acquisition	138	396
Angle changes	5	4
Beam energy changes	40	8
Spectrometer momentum changes	9	0
Checkout	24	24
Total	**216**	**432**

of the longitudinal cross section component σ_L. The statistical error on σ_L is given by the equation

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

which may be rewritten in terms of R to be

$$\frac{\Delta\sigma_L}{\sigma_L} \approx \sqrt{2}(\Delta\sigma/\sigma)\left(\frac{1+\epsilon R}{R}\right)\frac{1}{\Delta\epsilon}. \tag{3}$$

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 3. A value of $R = 0.06$ was assumed for all the tabulated calculations. The ϵ ranges are given in Table 3. It is to be noted that the proposed 5 GeV run plan includes three ϵ points for every L/T separation.

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

Table 4 shows our beam time request for this experiment as performed in two phases, with maximum energies of 5 and 6 GeV respectively. We assume that 800 MeV/pass and 1 GeV/pass will be standard accelerator tunes by the fall of 1997, thus requiring only 2 hours for these beam energy changes. We propose a non-standard tune of 900 MeV base energy and assume this will require 3 shifts (24 hours) to obtain. A non-standard tune has already been employed for the kaon experiment E93-018.

We require 26 quarter hour spectrometer angle changes for phase 1 during which the spectrometer central momentum may also be changed. These total 5 hours as some may be accomplished during beam energy changes. Phase 1 requires an additional 34 momentum changes at a quarter of an hour each, totalling 9 hours. Combined with one day for checkout, phase 1 may be accomplished in 9 days total.

Table 5: Systematic uncertainties at $Q^2 = 4.9$ (GeV/c)^2 for the Δ resonance during phase 1.

		ΔR
		$P_{33}(\Delta)$
Beam Steering	0.2 mrad	0.005
Beam Energy	$1 \cdot 10^{-3}$	0.028
Acceptance	0.2%	0.010
Scattering Angle	0.03^o (≈ 0.5 mr)	0.009
Beam Charge	$1 \cdot 10^{-3}$ relative	0.005
Target Density	$< 0.5\%$	0.027
Scattered Electron Energy	0.1%	0.009
Detector Efficiency	0.1%	0.005
Deadtime Corrections	0.1%	0.005
	Total	0.043

Phase 2 will complete the Q^2 coverage as proposed from $Q^2 \approx 5$ (GeV/c)^2 (now being accomplished in phase 1) out to $Q^2 \approx 7.5$ (GeV/c)^2. Phase 2 will take 18 days total, including 14 angular changes and 4 beam energy changes. There are no hours of overhead for changing spectrometer central momenta in the phase 2 request as these can all be accomplished during angle changes. We again request one full day for checkout.

The 18 days needed for phase 2, combined with the 9 days requested for phase 1, adds to a total beam time request of 27 days. This is two more days than the 25 days originally proposed. This is necessary because the original proposal took full advantage of simultaneous single arm running in HMS and SOS to minimize beam time, which cannot be done completely when running the experiment in two phases. Furthermore. in the present proposal, HMS has been used for the more sensitive delta resonance data taking, and 3 ϵ points are proposed to minimize systematic uncertainties. However, some beam time is saved since non-standard beam energies have been demonstrated.

Table 5 displays the effect (ΔR) of point-to-point systematic uncertainties on R, measured at the delta resonance with uncertainties which we expect to be obtainable in 1997 in Hall C. The values ΔR shown were calculated for $Q^2 = 4.9$ (GeV/c)^2 using cross sections from the global fit to SLAC inclusive resonance electroproduction data. The largest systematic uncertainties are from the beam energy and target density. An overall systematic error on R of $\Delta R \approx 0.04$ is expected.

The Collaboration

The E94-110 collaboration consists largely of locally-based people who have participated in every facet of Hall C commissioning. Collaboration members have been responsible for the design, construction, and commissioning of the HMS drift chambers, thin vacuum windows, hodoscope, and lead glass shower counter; and for the SOS drift chamber commissioning, and hodoscope and lead glass design, construction and commissioning. Collaboration members have designed, constructed, and commissioned the cryogenic

target and the beam current monitoring systems.

Spokesmen from four of the six completed Hall C experiments are collaboration members. At least two dissertation students and one postdoctoral research associate will be on site at TJNAF for the year preceding an experiment schedule date.

The collaboration has been implementing techniques to reduce systematical uncertainties in Hall C experiments, including detailed studies of spectrometer optics, spectrometer survey studies, raster phase analysis, and additional beam line instrumentation. This collaboration has the on-site experience and knowledge requisite to perform the proposed precision measurement.

Conclusion

Using the existing Hall C apparatus, it is possible to perform a global survey of longitudinal strength throughout the nucleon resonance region with an order of magnitude better precision than has been achieved before. The PAC 9 stated that this is a fundamental quantity that should be measured with the best possible accuracy. We have addressed in this update the PAC's concerns regarding systematic uncertainties and have discussed current Hall C capabilities to demonstrate that the measurement of $R = \sigma_L/\sigma_T$ can be achieved with the proposed precision. As requested by PAC 9, we present a modified two phase run plan for 5 and 6 GeV, allowing measurements of the entire resonance region up to $Q^2 \approx 5$ (GeV/c)^2 in the first phase. We request full approval of the first phase, and conditional approval of the second phase with demonstrated success of the first phase.

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