JLab PAC12 Proposal Cover Sheet

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

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

(Choose one)

- [x] New Proposal Title: Measurement of Hydrogen and Deuterium inclusive resonance cross sections at intermediate Q2 for Parton-Hadron duality studies.
- [ ] Update Experiment Number:
- [ ] Letter-of-Intent Title:

Contact Person

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Experimental Hall: C Days Requested for Approval: 3

Jefferson Lab Use Only

Receipt Date: 6/26/97 97-010

By:

LAB RESOURCES LIST

JLab Proposal No.: ____________ Date June 26, 1997

(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)*

The only non-standard equipment required is a target length limiting collimator on the SOS side.

New Support Structures:

Data Acquisition/Reduction

Computing Resources: This experiment will utilize the existing Hall C data acquisition hardware and software.

New Software:

Major Equipment

Magnets: This experiment uses the "standard" Hall C equipment.

Power Supplies:

Targets:

Detectors:

Electronics:

Computer Hardware:

Other:

Other:

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: ____________ (For CEBAF User Liaison Office use only.)

Date: June 26, 1997

Check all items for which there is an anticipated need.

Cryogenics
- ____ beamline magnets
- x analysis magnets
- x target
  - type: standard 15 cm
  - flow rate: Hall C
  - capacity: hydrogen and deuterium

Electrical Equipment
- ____ cryo/electrical devices
- ____ capacitor banks
- ____ high voltage
- ____ exposed equipment

none unique to this experiment

Radioactive/Hazardous Materials
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
- type: LH 2, LD2
- flow rate: (standard 15 cm)
- capacity: Hall C targets

Drift Chambers HMS, SOS
- type: standard
- flow rate: ____
- capacity: ____

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

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

General:

Experiment Class:
- x Base Equipment
- ____ Temp. Mod. to Base Equip.
- ____ Permanent Mod. to Base Equipment
- ____ Major New Apparatus

Other: ____

BEAM REQUIREMENTS LIST

JLab Proposal No.: ______________________ Date: June 26, 1997

Hall: C Anticipated Run Date: new proposal - could run at any time PAC Approved Days: ________

Spokesperson: Cynthia Keppel Hall Liaison: ______________________
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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)
1	5500	50	none	Hall C "standard"	15cm deuterium target	27
2	5500	50	none	Hall C "standard"	15 cm hydrogen target	27
3	5500	50	none	Hall C "standard"	15 cm aluminum	12
					"empty" target	

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.

PROPOSAL submitted to JLab PAC-12

Measurement of Hydrogen and Deuterium Inclusive Resonance Cross Sections at Intermediate Q^2 for Parton-Hadron Duality Studies

Submitted by

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Measurement of Hydrogen and Deuterium Inclusive Resonance Cross Sections at Intermediate Q^2 for Parton-Hadron Duality Studies

Abstract

We propose to extend measurements of inclusive nucleon resonance electroproduction cross sections from hydrogen and deuterium targets throughout the resonance region ($1 < W^2 < 4$ GeV^2) to span the four-momentum transfer range $0.5 < Q^2 < 7.5$ (GeV/c)^2. The cross sections will be used in conjunction with existing deep inelastic and elastic data for precision experimental tests of parton-hadron (Bloom-Gilman) duality in the nucleon structure functions. Substantial progress in understanding QCD and the concept of duality allows for measurement of the QCD moments of $F_2(x, Q^2)$ from resonance data in the moderate Q^2 region. The experimental F_2 moments may be used to extract the matrix elements of higher-twist operators.

We request three 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. The experiment will utilize the existing equipment in Hall C with 5.0 GeV or higher electron beam energy. Electrons scattered from 15 cm liquid hydrogen and deuterium targets will be detected in both the High Momentum Spectrometer (HMS) and the Short Orbit Spectrometer (SOS) in simultaneous single arm mode.

MOTIVATION

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 [1, 2]. Precisely, the prominent resonances in inclusive electron-proton scattering do not disappear with increasing four-momentum transfer squared (Q^2) relative to the background under them, but instead fall at roughly the same rate. Also, the smooth scaling limit seen at high Q^2 and large missing mass squared (W^2) for the structure function $\nu W_2(\omega')$ is an average of the resonance enhancements at the same ω', but lower Q^2 and W^2. Here, ω' is an "improved" scaling variable and is equal to $1+ W^2 / Q^2 = (2M\nu + M^2)/Q^2$. These observations are termed Bloom-Gilman duality, or local duality. Bloom and Gilman quantified the latter observation with the following equation:

$$\frac{2M}{Q^2}\int_0^{\nu_m} \nu W_2(\nu, Q^2) d\nu = \int_1^{(2M\nu_m+m^2)/Q^2} \nu W_2(\omega') d\omega'. \qquad (1)$$

Here, ν is the energy transfer. This observed duality relationship between resonance electroproduction and scaling behavior as observed in deep inelastic scattering suggests a common origin for both phenomena.

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. A QCD-based explanation of why the resonance structure functions average to the F_2 scaling curve was offered by De Rujula, Georgi, and Politzer in 1977 [3, 4]. While original studies were somewhat qualitative, enormous progress has been made in understanding QCD in the past two decades and recent work has focused once again on Bloom-Gilman duality [5, 6, 7, 8].

Currently, single arm hydrogen and deuterium resonance data obtained throughout the 1996 running period in Hall C at Jefferson Lab is being analyzed for the purposes of global fitting, form factor extraction, and parton-hadron duality tests. This proposal seeks to extend the new Jefferson Lab data with an experiment dedicated to precision tests of duality. Figure 1 displays preliminary Jefferson Lab inclusive nucleon resonance electroproduction spectra from hydrogen, plotted as a function of the Bloom-Gilman scaling variable ω'. The deep inelastic scaling limit curve is from a SLAC global fit [9]. Note that ω' is plotted on a logarithmic scale.

There exists a large body of precision deep inelastic lepton-nucleon scattering data. Combined with precision resonance data, it will be possible to rigorously study the observations and predictions of duality. Duality will be tested for the neutron by subtraction of the kinematically-matched proton data, using smearing and deuteron wave function modelling. It will also be interesting to test parton-hadron duality on the deuteron itself as a hadron.

An alternative approach to interpretation of the proposed data is to assume equation 1 to be valid as predicted from QCD. It is then possible to study the interplay between resonances and higher twists. The Q^2 dependence of the moments of the structure functions is given by

$$M_n(Q^2) = \int x^{n-2} F(x, Q^2) dx, \qquad (2)$$

where x is the Bjorken scaling variable. The moments $M_n(Q^2)$ of F_2 may be expressed following the operator product expansion and can be expanded in powers of Q^{-2} and depend on the nucleon matrix elements of higher-twist operators composed of quark and gluon fields. Ji [6] defines a kinematic region where higher-twist corrections become important, but stay perturbative, and thus only the first few terms in the twist expansion are of practical importance. The scattering in this region is described by few parton processes. In the four momentum transfer region $Q^2 < 10$ (GeV/c^2), the resonance contributions to the moments are significant. Here also the higher-twist corrections are perturbative, so the moments are not very different from those at larger Q^2. In this region, then, the resonances must follow the deep inelastic curve apart from perturbative higher-twist corrections. Or, conversely, the behavior of the resonances is constrained by the higher twist expansion. Since deuterium is a spin-1 nuclear target, another class of twist-four operators is theoretically possible. The kinematic region of the proposed data may be described in terms either of resonance production or the scattering of a few partons: parton-hadron duality.

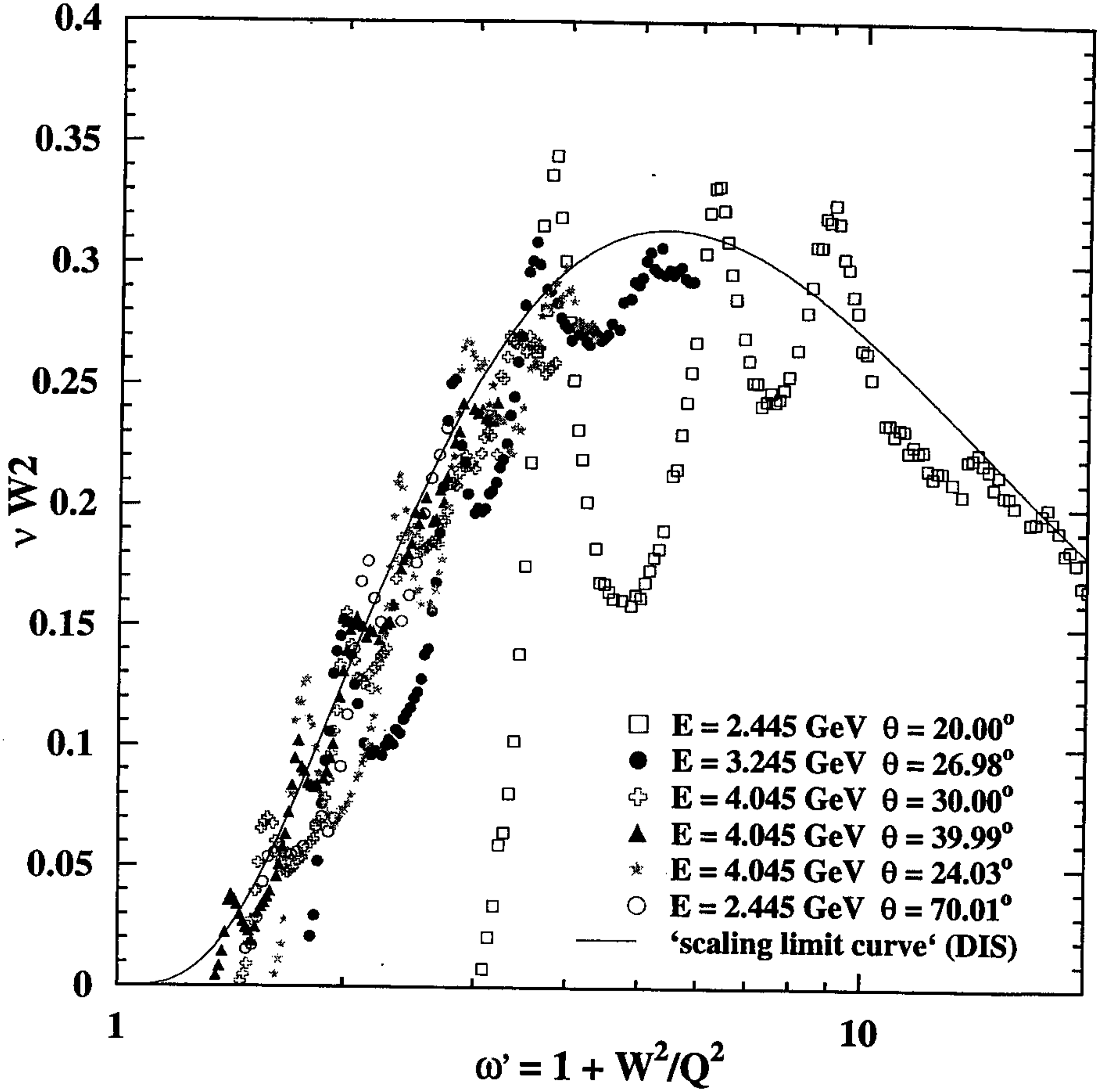

Figure 1: Preliminary inclusive nucleon resonance electroproduction data from Hall C at Jefferson Lab. The deep inelastic form factor and resonance region structure function curves are from SLAC global fits.

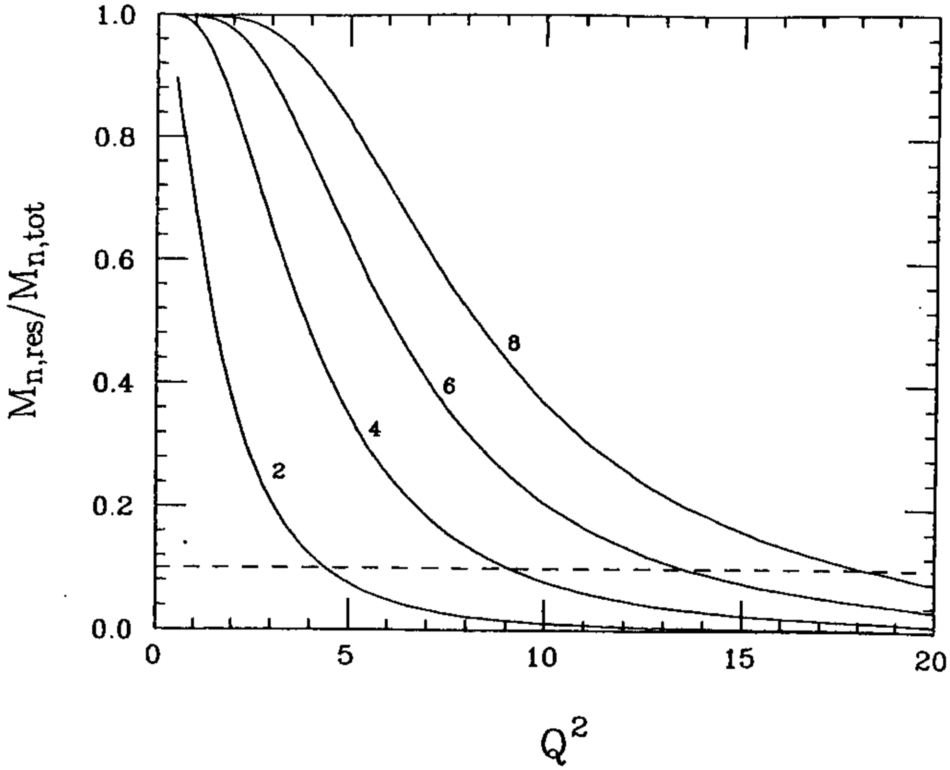

Figure 2: Ratio of the moments from the resonance region, including the elastic contribution, to that of the total [6].

The primary goal of this duality study is, with the new resonance region data, to extract the matrix elements of higher-twist operators. The non-resonance experimental data have already shown the higher-twist effects [10]. Figure 2 (reference [6]) depicts the ratio of the F_2 moments from the resonance region, including the elastic contribution, to that of the total as a function of Q^2. Conversely, it will be possible to employ higher-twist contributions, either from theoretical calculations or extracted from deep inelastic data, to determine nucleon resonance properties.

EXPERIMENT

Figure 3 depicts the proposed (solid circles) and existing (open circles) inclusive resonance kinematics to be obtained from hydrogen and deuterium targets in Hall C. The circles are central spectrometer settings and the lines connecting them the full kinematic coverage which will be obtained in the spectrometer acceptance. There will be adequate kinematic overlap between spectrometer settings for acceptance checks. The large vertical dashed lines bound the kinematic region between elastic scattering and the deep inelastic threshold. All spectra obtained will include the elastic (or quasi-elastic) peak and most will also include deep inelastic ($W^2 \geq 4.0$ GeV^2) data.

We propose to use the highest beam energy available at the time of the experiment. Table 1 lists the kinematics assuming a 5.5 GeV beam energy. We note that the count

Table 1: 5.5 GeV Kinematics

W^2	Q^2	E′	Θ	rate	time
$(GeV/c)^2$	$(GeV/c)^2$	GeV/c	deg	Hz	hours
HMS					
1.50	4.32	2.91	30	128	0.5
2.51	3.88	2.61		378	0.5
3.52	3.43	2.31		656	0.5
1.50	5.05	2.52	35	37	1
2.51	4.53	2.26		137	0.5
3.52	4.01	2.00		257	0.5
1.50	5.68	2.19	40	13	2
2.51	5.09	1.96		59	0.5
3.52	4.50	1.74		116	0.5
1.48	6.66	1.68	50	3	8
2.48	5.97	1.51		15	2
3.46	5.31	1.34		33	1
TOTAL					17.5
SOS					
1.50	4.32	2.91	30	34	1
2.51	3.88	2.61		100	0.5
3.52	3.43	2.31		175	0.5
2.26	6.98	1.09	65		25
1.50	*7.56*	*1.18*		*0.3*	*(50)*
2.51	*6.79*	*1.06*		*1.6*	*(9)*
3.50	*6.02*	*0.94*		*3.6*	*(4)*
TOTAL					27

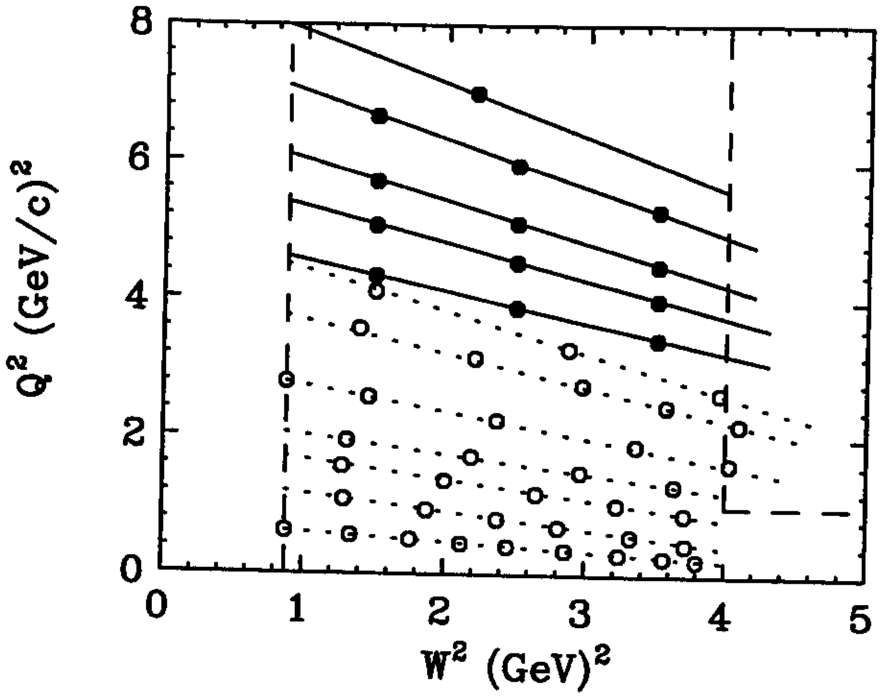

Figure 3: Plot of the proposed (solid circles) and existing (open circles) inclusive resonance kinematics from hydrogen and deuterium targets in Hall C. Dashed lines represent regions of spectra overlap with elastic and deep inelastic kinematics.

rates are not very sensitive to the exact beam energy, and the proposal could run with a beam energy of 5.0 GeV as well. The count rates specified are for hydrogen (LH2); we request similar data acquisition times for deuterium (LD2). We will use 15 cm long LH2 and LD2 targets, and have assumed a beam current of 50 μA. We will utilize the large ($\pm$20%) momentum acceptance of the SOS spectrometer to measure the full W^2 range at the largest backward angle at one setting, but have specified the count rate estimates at several W^2 points in Table 1 (italicized). SOS will only see 4 cm of the extended target. Therefore, we propose to use target length limiting collimators on the SOS side. SOS and HMS will simultaneously measure the smallest angle data for cross calibration.

In almost all cases we will accumulate more than 50K statistics, which corresponds to a 2% statistical uncertainty for a W^2 bin of 0.05 (GeV/c)^2. The only exception is the largest SOS angle, where the statistical uncertainty in the low W^2 region will be slightly worse. Previous Hall C experiments indicate a 3% systematic uncertainty in total cross section measurements.

Since the nominal running time for data acquisition with HMS is less than with SOS (2×17.5 compared to 2×27), HMS will also be utilized to measure positron rates to quantify pair production rates at the large backward angles. We calculate a worst case 1% positron contribution at the 40° scattering angle, and a worst case 3% positron contribution at the 65° scattering angle.

We also require separate running time for dummy ("empty") target running, and time for spectrometer momentum changes. We have assumed a 30 minute overhead for each spectrometer momentum change, which is larger than the 10 minute stabilization

Table 2: Beam time request

Data acquisition (LH2+LD2)	2×27
Dummy Running	12
11 momentum changes	6
Total (hours)	**72**

time typically used for Hall C experiments in 1996. Angle changes will be simultaneous with momentum changes.

SUMMARY

We request a total time of 72 hours (3 days) to measure high-precision resonance region cross sections on both LH2 and LD2 targets. The beam time request is summarized in Table 2. This beam time request extends the high precision LH2 and LD2 resonance region database up to momentum transfers of about 7 $(\mathrm{GeV/c})^2$, enabling precision tests of Bloom-Gilman local duality or, conversely, the extraction of higher twist effects.

References

[1] E.D. Bloom and F.J. Gilman, Phys. Rev. D4, 2901 (1970)

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[3] A. DeRujula, H. Georgi, and H.D. Politzer, Phys. Lett. B64, 428 (1977)

[4] A. DeRujula, H. Georgi, and H.D. Politzer, Annals Phys. 103, 315 (1977)

[5] C.E Carlson and N.C. Mukhopadhyay, Phys. Rev. D47, R1737 (1993)

[6] X. Ji and P. Unrau, Phys. Rev. D52, 72 (1995)

[7] V.M. Belyaev and A.V. Radyushkin, Phys. Lett. B359, 194 (1995)

[8] G. West, preprint, hep-ph/9612403 (1996)

[9] L.W. Whitlow et al., Phys. Lett. B250, 193 (1990)

[10] M. Virchaux and A. Milsztajn, Phys. Lett. B 274, 221 (1992)