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Contact Person

Name: JIANGUO ZHAO
Institution: Massachusetts Institute of Technology
Address: Rm 26-452.
Address: 77 Mass. Ave.
City, State, ZIP/Country: Cambridge, MA 02139
Phone: (617) 258-5438 Fax: (617) 258-5440
E-Mail: JZHAO@MITLNS.MIT.EDU.

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TJNAF PROPOSAL

Initial Exploration of Semi-exclusive Scattering in $x > 1$ Region with $^{3,4}He(e, e'p)$ Reactions

W. Bertozzi (co-spokesperson), S. Gilad (co-spokesperson), K. Fissum, D. Rowntree,
J. Zhao (Spokesperson), Z. Zhou
Massachusetts Institute of Technology

J. Templon
University of Georgia

M. Epstein
California State University, Los Angeles

and

The Hall-A Collaboration

Abstract

We propose to study high momentum components in $^{3,4}He$ via $(e,e'p)$ reactions at large Q^2 and $x > 1$ in the missing energy range from the two-body breakup into the continuum. At $Q^2 \simeq 2$, 3 (GeV/c)^2, we propose to measure in parallel kinematics the $^{3,4}He(e,e'p)$ cross-sections at $y = -300$ MeV/c ($x = 1.61, 1.51$, respectively) and, further away from the quasi-elastic peak, at $y = -450$ MeV/c ($x = 1.98, 1.80$, respectively). To further our understanding of the underlying currents, a separation of the longitudinal(L)/transverse(T) structure functions in $^3He(e,e'p)$ is proposed at $Q^2 \simeq 2$ (GeV/c)^2 and $y = -300$ MeV/c ($x = 1.61$). These systematic studies of the semi-exclusive reactions in the $x > 1$ side of the quasi-elastic peak will provide new detailed information on high momentum components and NN correlations in nuclei and will help to constrain modern theoretical calculations on few-body systems. The kinematics are selected such that meson exchange currents and final state interaction effects will be suppressed. Hence, NN correlations in nuclei can be studied with less ambiguity.

I. Introduction

The nucleon-nucleon interaction is of fundamental interest in nuclear physics. While its long and intermediate range properties are described by meson exchange, little is known about its short distance behavior. Lack of experimental understanding of the short-range-correlations (SRC) of NN pairs in nuclei has been a long standing problem in nuclear physics. high momentum components of the wave functions are associated with SRC. Therefore, studies of high momentum components are closely coupled to understanding of short-range behavior of nucleons in nuclei.

Past studies of inclusive (e,e') and semi-exclusive (e,e'p) scattering from nuclei have established that the quasi-free description of electron scattering from target nucleons does not provide the complete picture of electro-nuclear interactions. Meson exchange currents (MEC), isobar configurations (IC), final state interactions (FSI) and SRC must be included. To enhance the role of correlations, it is useful to go away from quasi-elastics (QE) kinematics which is dominated by the single-particle picture. With medium beam energies, this is typically done by going to the "dip" region where MEC, IC and FSI play important roles. To reduce the effects of MEC and IC it is preferred to go to the low energy transfer (ω) side of the QE peak as well as increasing the momentum transfer (q). In the case of high q, ejected hadrons have high enough momentum so that FSI becomes less important and is also better described by theory.

$^{3,4}He$ nuclei are of particular interest since they are relatively simple, yet differ in density. Modern calculations (Faddeev and variational calculations) provide improved initial state wave-functions [1, 2, 3]. In the case of ^{3}He, full Faddeev calculations are now possible for steadily increasing final state energies [4, 5]. These calculations need to be tested by studying critically different aspects of the wave functions and currents. A detailed and sufficient quantity of experimental data will help to constrain the theoretical calculations and improve our understanding of these nuclei.

II. Physics Motivations

SRC arise when two nucleons interact at a small distance at which the NN interaction is dominated by the strong repulsive core. This feature is a general property of correlated pairs in nuclei, therefore it should be similar for different nuclei. One should find similarities in the high momentum structure of different nuclei. Theoretical calculations of momentum distributions in nuclei performed within non-relativistic framework but using realistic NN potentials indicate that, to a good approximation, the momentum distribution of the nucleus at $p \geq p_o \simeq 300$ MeV/c can be represented by [10, 11]

$$n_A(p) \simeq a_2(A) n_2(p) \tag{1}$$

where n_2 is the contribution of nucleon pair correlation and is independent of A. In semi-exclusive $(e, e'p)$ reactions, one should find a ridge in the missing momentum and missing energy plane given by

$$E_m = \omega - T_p \simeq p_m^2 / 2m_N \tag{2}$$

where the spectral function $S(E_m, p_m)$ is enhanced.

The signals of SRC are normally hidden by competing processes such as MEC and FSI. It was shown that the FSI of the struck nucleon, evaluated with an optical potential, totally overwhelms the effects from ground state NN correlations [12]. Nonetheless, in Ref. [13] the relevance of NN correlations on the inclusive cross-section in the region $1 < x < 2$ has been again advocated, arguing [11] that in that region, since scattering from a nucleon at rest is kinematically forbidden, the contribution from a correlated NN pair in a nucleus should be proportional to that in the deuteron. Increasing the ejected hadron momentum will suppress multi-step scattering processes. More recently, it has been shown that, in the case of light as well as complex nuclei, the inclusive cross-section at $Q^2 > 1$ $(\text{GeV/c})^2$ and $1.3 < x < 2$ is dominated by the absorption of the virtual photon on a pair of correlated nucleons and by their elastic re-scattering in the continuum [9]. Both initial state correlations and final state interactions resemble the ones occurring in the deuteron (apart from the *c.m.* motion and the binding of the pair in the complex nucleus).

In semi-exclusive reactions, the excitation of the residual nuclear system, E_m, is measured. It can be easily chosen so that the momenta entering in the ground state wave function would be larger than the Fermi-momentum, k_F. Calculations of FSI diagrams within the generalized eikonal approximation in Ref. [15] show that in addition to $x > 1$, the condition:

$$|p_{mz} + \frac{q_0}{q} E_m| \geq p_F \tag{3}$$

will confine the FSI within the short range correlated pair (Where p_{mz} is the longitudinal part of the missing momentum. In the case of parallel kinematics, p_{mz} is the same as measured p_m).

Inclusive reactions (e, e') have been used to study nuclear structure and dynamics for a long time. Early inclusive scattering data from SLAC at high Q^2 and in the $x > 1$ region show $y-$scaling and the necessity of including short-range-correlations (SRC) to match the measured strength in the low energy transfer (ω) side of the QE peak [6, 7]. When Faddeev wave functions generated by NN potential models were used, calculations underestimated the strength for $|y| > 200$ MeV/c. By introducing phenomenologically high momentum component to the wave functions (or y-scaling functions), one can fit the inclusive data well [6, 7, 8]. I. Sick *et al* multiplied the Faddeev spectral function by the empirical function

$$f(k) = 1 + (k/k_o)^n \tag{4}$$

with $n = 2.5$ and $k_o = 285$ MeV/c. The consequent increase in the high momentum components helps fit the data well over the whole region (fig. 1). This work suggests that a good region to look for SRC is $q > 800$ MeV/c and $x > 1$. Recently, Ciofi degli Atti and West [8] introduced a similarly motivated function of the form $B \cdot e^{-b|y|}$ ($b \simeq 1.18$ fm^{-1}) for large y which fits the inclusive data very well with b independent of A. They concluded that this reflects a universal aspect of short range NN correlations in nuclei. Other theoretical studies over the years also suggest that the best kinematics to look for short range correlations is at high initial nucleon momentum and $x > 1$ [6, 7, 8, 9, 10, 11]. This proposal is designed to take advantage of some of these ideas.

The negative y region ($x > 1$) has other attractive properties. First, the contribution of nucleon resonances (e.g. the Δ) is substantially reduced due to the lower energy transfers involved. Second, since $y-$scaling behavior is observed at high Q^2 from the SLAC data (see fig. 2), one can be reasonably certain that meson-exchange contributions are not large since there is no apparent reason that MEC should scale [7].

We propose to measure cross-sections for the $(e, e'p)$ reactions which can be related to measuring $n_A(p)$ (eq. 2) for both ^3He and ^4He at different high values of Q^2 and y ($x > 1$). Cross-sections at high p_m will be measured both for the two-body breakup and missing energy continuum. Spectral function $S(E_m, p_m)$ around the ridge will be studied.

Since the longitudinal (L) and transverse (T) components of the cross-section correspond to different couplings, coulombic and magnetic, respectively, the requirement that the calculations reproduce both simultaneously provides a stringent test of our understanding of the currents involved and the reaction mechanisms. The MEC are mainly transverse in character. The longitudinal response offers the possibility of a clean probe for SRC effects in the spectral function. Hence, we also propose to do an L/T separation at $Q^2 = 2$ (GeV/c)^2 and $y = -300$ MeV/c for the $^3He(e, e'p)$ reaction. When combined with the cross-sections at different high Q^2's and $|y|$'s, it should help to disentangle the SRC signals. The separated L/T response functions may provide unique insights on the anomaly observed in the recently published Saclay data [18] at similar $p_m = 260$ MeV/c, but in the dip-region and low Q^2 where MEC and FSI contribute significantly.

III. Other Recent Related Experimental Studies

There are a number of recent data collected at different laboratories. But the overall amount of data is still scarce. In particular, there is no semi-exclusive data in the low energy transfer region (ω) of the QE peak ($x > 1$) or at high Q^2 (> 1 (GeV/c)^2) where we propose our measurement. We give a brief summary of what has been done in this section.

The signals of correlations have been observed in recently published Saclay experiments on $^{3,4}He(e,e'p)$ reactions in the dip-region [16, 17]. Indication of bumps corresponding to $(E_m)_c = M_p + M_{np} - M_{^3He} \simeq p_m^2/4m_p$ for different θ_{pq} were observed in the missing energy continuum for $^3He(e,e'p)$ (see fig. 3). The data show some agreement with a calculation of Laget [19]. In the two-body breakup channel, the cross-section exceeds PWIA significantly when $p_m > 400$ MeV/c. It was suggested that this is due to absorption of a virtual photon on a quasi-deuteron with the spectator proton being detected. Results from the $^4He(e,e'p)$ reaction are inconsistent with theoretical calculations both in the two-body breakup and the continuum [17]. In the missing energy continuum, three data points with $p_m > 350$ MeV/c indicate the effects of correlations and are in fair agreement with calculation of Laget [20]. Three data points with $250 < p_m < 350$ MeV do not show any indication of correlations. This is not understood. The momentum distribution after corrections show similarities for ^3He, ^4He and ^2D. In the two-body breakup channel, the data significantly disagree with calculations which include MEC and FSI.

NN correlations were also investigated by $^4He(e,e'p)$, and $^4He(e,e'pp)$ reactions at Bonn [21], also in the dip-region and at five different $\omega's$. NN correlations were identified by a bump in the missing energy continuum in the $(e,e'p)$ channel at $\omega = 275$ MeV. There again, the bump is not well described by calculations of Laget [20] which include MEC and FSI.

An L/T separation was performed for the $^3He(e,e'p)$ reaction in the dip-region at recoil momentum of 260 MeV/c [18]. The longitudinal spectral function is strongly quenched relative to the transverse both in the two-body breakup and in the continuum. The ratio of longitudinal to transverse in the continuum is much smaller (more than a factor of 2) than model calculations [20] taking into account FSI and MEC (see fig. 4).

As can be seen, existing data, as discussed above, provide indications of SRC and some agreement with theoretical calculations, but also show anomaly and disagreement with the same calculations.

At MAMI, there is a comprehensive program to separate longitudinal and transverse structure functions in $^{3,4}He(e,e'p)$ in order to study nuclear currents and the reaction mechanisms. The data cover the missing energy range from two-body breakup to 200 MeV [26]. Data analysis is in progress. As part of this program, the y-dependence ($y = -200, 0, +140$ MeV/c) of R_L and R_T in $^{3,4}He(e,e'p)$ is studied [26]. These high accuracy data in combination with modern theoretical calculations will shed light on the nuclear currents and interactions in these few-body systems. Our proposal takes these measurements to the high Q^2 domain and extends y to -450 MeV/c.

This proposal is also complementary to and takes a step further than the Hall-C experiment 89-008 [24] which is inclusive scattering from nuclei at $x > 1$ and high Q^2.

Our proposal is also complimentary to the approved Hall-A proposal on $^3He(e,e'p)$ experiment E-89-044 [25] (720 hours). That experiment concentrates on the QE peak and "dip" kinematics ($x \leq 1$) to separate response functions, while our proposal emphasizes the $1 < x \leq 2$ region.

There are no semi-exclusive data, either total cross-sections or separated response functions, in the low energy transfer (ω) side of the QE peak on $^{3,4}He(e,e'p)$ reactions. High precision data from this proposed experiment and other approved experiments can provide very useful information to constrain theoretical calculations and hopefully reveal long expected SRC signals.

IV. Experimental Considerations - kinematics, rates etc.

We proposed to measure cross-sections of the $^{3,4}He(e,e'p)$ reactions for the two-body breakup and the continuum at $y = -300$ and -450 MeV/c. This will give us a range of missing momentum for similar missing energy bins. The distribution of the spectral function $S(E_m, p_m)$ can be studied and SRC can be searched for around the ridge of $E_m = p_m^2/2m$ (eq. (3)). We propose to study the Q^2 dependence of the cross-sections by measuring the cross-sections at each y value with two different Q^2's (2 and 3 (GeV/c)^2). As discussed earlier, the difference in spectral functions at different Q^2's in the same E_m and p_m range will provide information on MEC and FSI.

We propose to measure cross-sections on both ^3He and ^4He nuclei to search for similarities in the high momentum components distributions, therefore to study the similarities of NN correlations in these nuclei.

An L/T separation is also proposed for the $^3He(e,e'p)$ reaction at $Q^2 = 2$ (GeV/C)^2, $y = -300$ MeV/c ($x = 1.6$). These data will also provide insight on the effects of MEC and FSI and will provide a stringent test for theoretical calculations. This may also help to understand the L/T anomaly observed in the Saclay experiment [18].

We take advantage of the two high resolution spectrometers in Hall-A to study both $^{3,4}He(e,e'p)$ reactions at the two-body breakup and in the continuum. These data will cover a missing energy range from two-body breakup to 100 MeV (for some kinematiccal settings up to 150 MeV) and missing momentum of 200 to 600 MeV/c. Figure 5 shows a simulated distribution of $E_m - p_m$ acceptance at $Q^2 = 2$ (GeV/c)^2, $y = -300$ MeV/c and $x = 1.6$).

The kinematic acceptance and counting rates for $^3He(e,e'p)$ reaction were calculated with the computer Monte Carlo code MCEEP with a spectral function of Meier-Hajduk *et al* [1] for ^3He and its modified version from I. Sick [27]. Hall-A spectrometer parameters and a luminosity of $1 \times 10^{38}\text{cm}^{-2}\ \text{sec}^{-1}$ were assumed. Table 1 shows the rates and beam time required. The rates are for the two-body breakup and the continuum. The beam time requested is for acquiring a 2% statistical accuracy in the $E_m = 40 - 50$ MeV bin (see figs. 6 and 7 which are sample distributions E_m and p_m from the simulation). The beam time required to measured the cross-sections of $^3He(e,e'p)$ at $Q^2 = 2$, $3(\text{GeV/c})^2$ and $y = -300, 450$ MeV/c is **220 hours.**

Since there is no spectral function for the ^4He missing energy continuum, we estimate the rates based on the ratio of $^3He(e,e'p)^2H$ and $^4He(e,e'p)^3H$ cross-sections. Taking the ratio of the cross-sections to be 1.25 and the Hall-A cryo-target density ratio for ^4He to ^3He to be $0.15/0.093 \simeq 1.6$, the rates for $^4He(e,e'p)$ in the same kinematic region are about 2 times higher than for the $^3He(e,e'p)$ reaction. Therefore, the beam time required for the same cross-section measurements on ^4He is about **110 hours**.

Table 2 shows the counting rates and beam time estimation for the L/T separation of the $^3He(e,e'p)$ reaction with three virtual photon polarizations. The beam time requested is for acquiring 2% statistical accuracy in the E_m bin of 40-50 MeV over the p_m range in the acceptance. Very limited $\omega - q$ acceptance is used for the forward setting to match the restricted $\omega - q$ acceptance of the backward setting (see fig. 8). The beam time required to do the L/T separation of $^3He(e,e'p)$ at $Q^2 = 2$ $(\text{GeV/c})^2$, $y = -300$ MeV/c ($x = 1.61$) and three virtual photon polarizations is **380 hours**.

The estimated singles counting rates and accidental coincident rates with the ^3He target are shown in Table 3. The singles counting rates (those observed in the electron spectrometer originating from (e,e') and (e,π^-) reactions and in the hadron spectrometer

Table 1: **The rates and beam time estimates for $^3He(e,e'p)$.**

KIN	Q^2 $(GeV/c)^2$	y (MeV/c)	x	two-body breakup (counts/hour)	continuum (counts/hour)	beam time (hours)
$KIN1$	2	-300	1.61	3433	4099	10
$KIN2$	3	-300	1.51	494	689	40
$KIN3$	2	-450	1.98	127	549	35
$KIN4$	3	-450	1.80	29	136	135

The beam time required is estimated to achieve a 2% statistical accuracy in the E_m bin of 40-50 MeV over the p_m range in the acceptance. This is for ^3He only. Beam time required for ^4He will be about 50% of the above numbers, as discussed in the text.

originating from (e,p) and (e,π^+) reactions) were estimated with the computer codes QFS and EPC of Lightbody and O'Connell [29]. Accidental coincidence rates were calculated assuming a coincidence timing width of 2 ns and a duty factor of 100%. The listed accidental rates are over the whole missing energy range within the momentum acceptances of the spectrometers. The accidental coincidence rates are insignificant compared to the true coincident rates for all kinematics considered.

Systematic errors associated with uncertainties of beam energy, spectrometer angular positions and particle momenta, and normalizations are estimated and listed in table 4.

The errors on the separated response functions have been estimated with assumed accuracies of the measured cross-sections and relative strength of the L/T response functions. Table 5 shows the estimates.

Table 2: **Rates and beam time estimates for the L/T separation of $^3He(e,e'p)$**

KIN	Beam energy (MeV)	θ_{pq} (degree)	ϵ	two-body breakup (counts/hour)	continuum (counts/hour)	Beam time (hours)
KIN_F	4045	0	0.92	845	634	85
KIN_M	2445	0	0.76			125
KIN_B	1645	0	0.48	505	350	170

The beam time required is to achieve a 2% statistical accuracy in the E_m bin of 40-50 MeV over the p_m range in the acceptance at y = -300 MeV/c ($x = 1.61$) and Q^2 = 2 (GeV/c)^2. Phase spaces have been matched for forward-backward settings.

V. Commitment of the Collaboration

This experiment is proposed as a Hall-A collaboration experiment. There will be graduate students available from MIT or other institutions to work on the experiment as their Ph.D. dissertations. We do not expect any problem in terms of manpower for this experiment.

VI. Summary

We proposed to measure cross-sections of $^{3,4}He(e,e'p)$ for the two-body breakup and the continuum at large Q^2 and $x > 1$ with two Q^2's and two y values. High momentum components of the wave-functions will be studied. Kinematics are chosen to enhance SRC and suppress competing currents. Longitudinal and transverse response functions will be separated for $^3He(e,e'p)$ at $Q^2 = 2$ (GeV/c)^2 and $y = -300$ MeV/c ($x = 1.6$) for the two-body breakup and the missing energy continuum. This will help to further characterize the underlying currents and reaction mechanisms. This experiment will provide

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Systematic errors associated with uncertainties of beam energy, spectrometer angular positions and particle momenta, and normalizations are estimated and listed in table 4.

The errors on the separated response functions have been estimated with assumed accuracies of the measured cross-sections and relative strength of the L/T response functions. Table 5 shows the estimates.

Table 5: **Estimates of the errors on the separated L/T response functions.**

$(\delta\sigma/\sigma)$ (%)	R_L/R_T	$\delta R_L/R_L$	$\delta R_T/R_T$
3%	1.0	13%	14%
	0.5	19%	11%
	0.2	36%	9%
4%	1.0	17%	19%
	0.5	25%	14%
	0.2	49%	11%

These estimates assume errors on the cross-sections to be 3% and 4%. Assumptions are also made on the relative strength of the L/T response functions.

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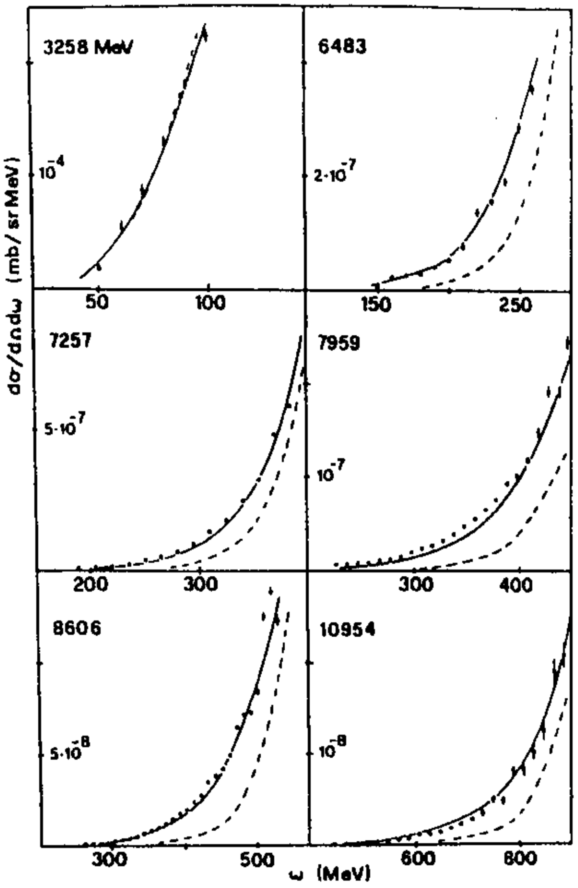

Figure 1: Quasi-elastic scattering cross-section as a function of energy loss from SLAC. The solid (dashed) curves are calculated using modified (unmodified) Faddeev spectral function [6]

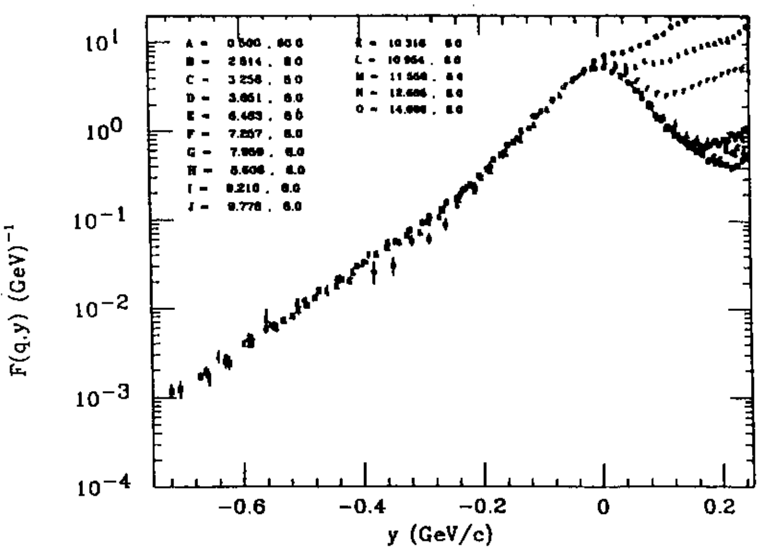

Figure 2: Experimental scaling functions from SLAC for ^3He [7]. The letters label different incident electron energy scattering angle pairs (ϵ, θ) in (GeV, degrees).

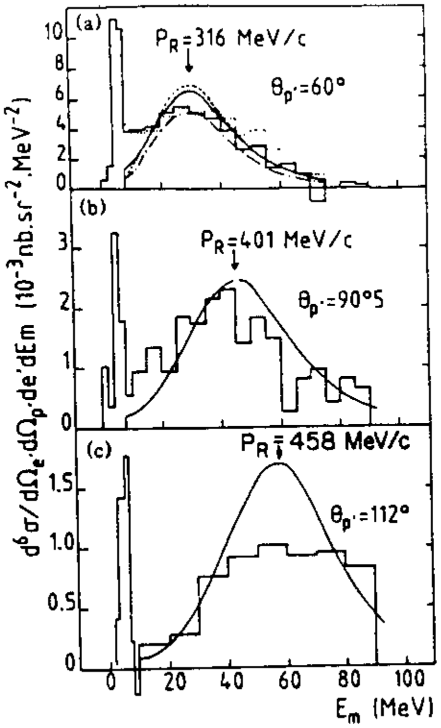

Figure 3: Cross-section for $^3He(e,e'p)$ vs. E_m from Saclay [16]. Curves are theoretical predictions. Bumps are indication of SRC.

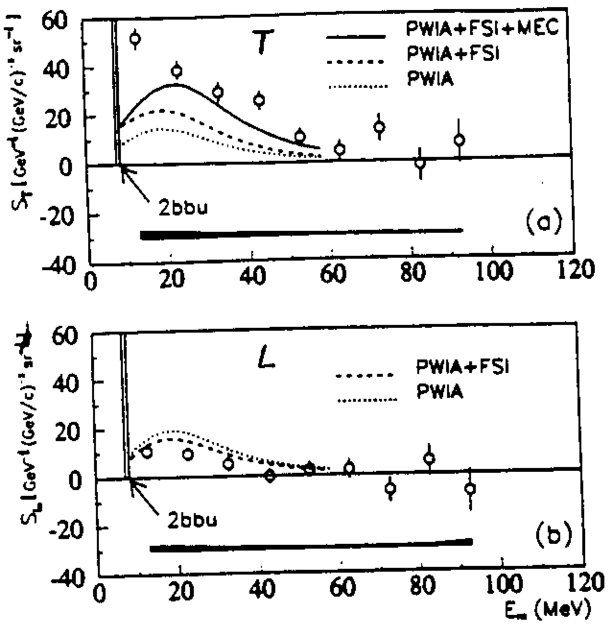

Figure 4: Longitudinal (a) and transverse (b) experimental spectral function from Saclay in continuum channel [18]. Curves are theoretical calculations.

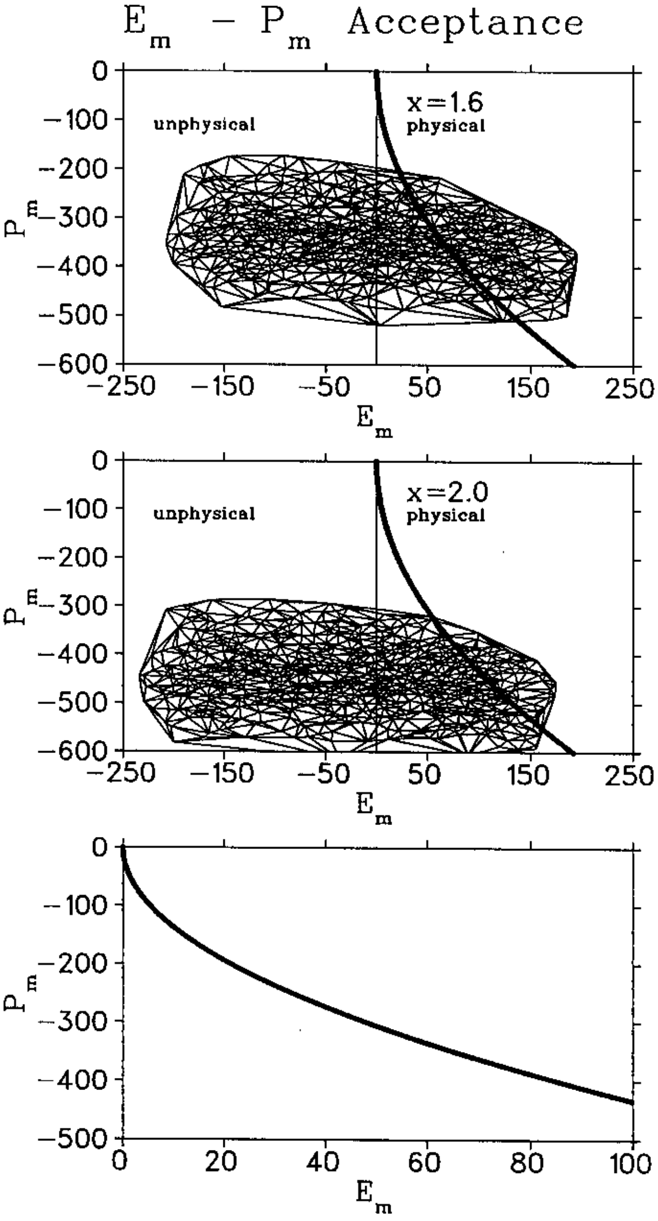

Figure 5: Simulated missing energy (E_m) and missing momentum (p_m) acceptance for the $Q^2 = 2$ (GeV/c)^2 setting, at $x = 1.6$ and 2.0 (y = -300 and -450 MeV/c), respectively. The ridge is corresponding to $E_m = p_m^2/2m$. when $p_m > p_F$, where the spectral function should be peaked due to SRC.

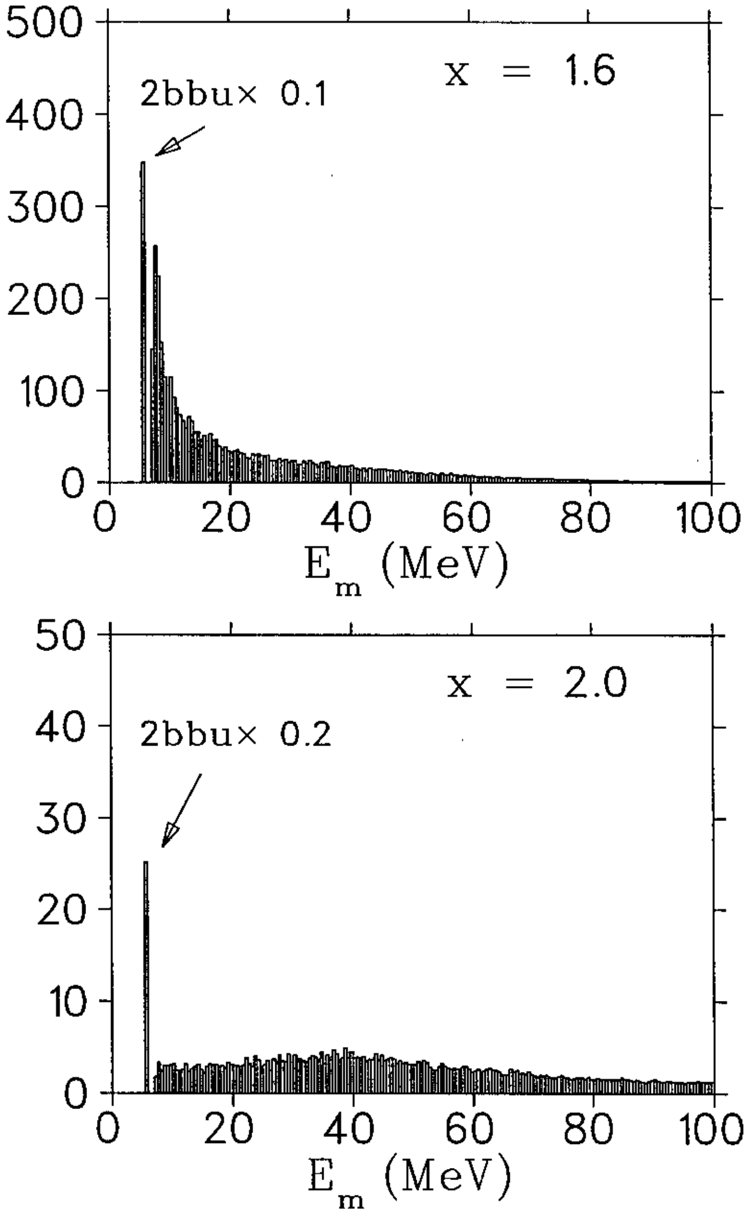

Figure 6: Simulated missing energy (E_m) distributions for counting rates estimate at the $Q^2 = 2$ (GeV/c)^2, $x = 1.6$ and 2.0 ($y = -300$ and -450 MeV/c), respectively.

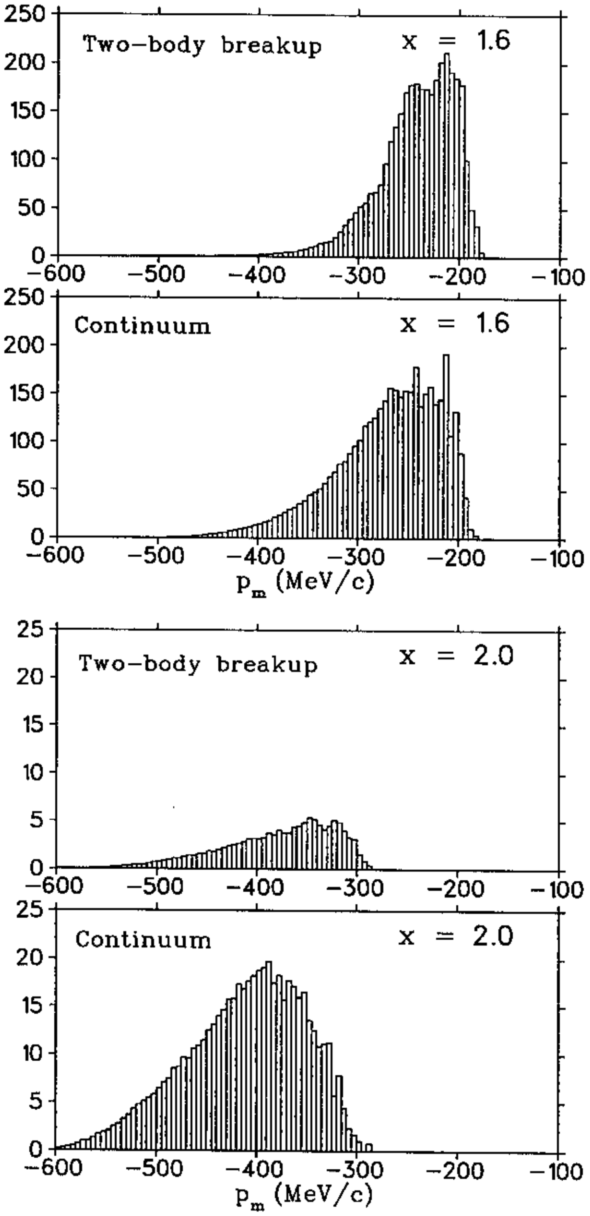

Figure 7: Simulated missing momenta (p_m) distributions for $^3He(e,e'p)$ two-body breakup and continuum at the $Q^2 = 2$ (GeV/c)^2, $x = 1.6$ ($y =$ -300 MeV/c), and $x = 2.0$ ($y = -450$ MeV/c), respectively.

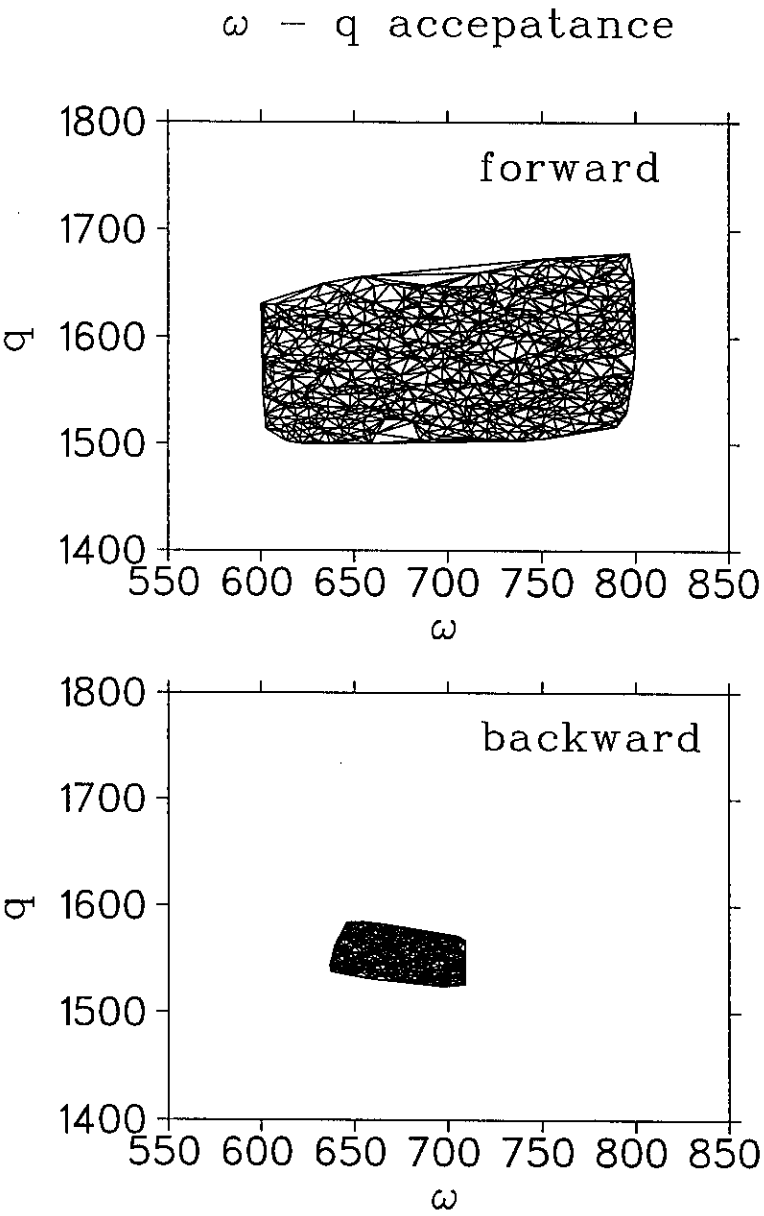

Figure 8: Phase space acceptances of $\omega - q$ at $Q^2 = 2$ (GeV/c)^2, $x = 1.6$ and $y = -300$ MeV/c for L/T separation as obtained from the simulations. The forward acceptance has been cut to match the limited acceptance for the backward setting.

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)*

No

New Support Structures: No

Data Acquisition/Reduction

Computing Resources: Standard

New Software: No

Major Equipment

Magnets: standard

Power Supplies: standard

Targets: standard cryogneics target

Detectors: standard

Electronics: Standard

Computer Hardware: Standard

Other: No

Other:

HAZARD IDENTIFICATION CHECKLIST

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

Check all items for which there is an anticipated need.

Cryogenics
____ beamline magnets
✓ analysis magnets
✓ target
type: ^{3,4}He
flow rate: ________
capacity: ________

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

Radioactive/Hazardous Materials
List any radioactive or hazadorous/ toxic materials planned for use:
____
____
____
____

Pressure Vessels
____ inside diameter
____ operating pressure
____ window material
____ window thickness

Flammable Gas or Liquids
type: ________
flow rate: ________
capacity: ________

Drift Chambers
type: ________
flow rate: ________
capacity: ________

Other Target Materials
____ Beryllium (Be)
____ Lithium (Li)
____ Mercury (Hg)
____ Lead (Pb)
____ Tungsten (W)
____ Uranium (U)
____ Other (list below)
____
____

Vacuum Vessels
____ inside diameter
____ operating pressure
____ window material
____ window thickness

Radioactive Sources
____ permanent installation
____ temporary use
type: ________
strength: ________

Large Mech. Structure/System
____ lifting devices
____ motion controllers
____ scaffolding or
____ elevated platforms

Lasers
type: ________
wattage: ________
class: ________

Installation:
____ permanent
____ temporary

Use:
____ calibration
____ alignment

Hazardous Materials
____ cyanide plating materials
____ scintillation oil (from)
____ PCBs
____ methane
____ TMAE
____ TEA
____ photographic developers
____ other (list below)
____
____

General:

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

Other: ____________________
____

BEAM REQUIREMENTS LIST

'Lab Proposal No.: ______ Date: ______

Hall: A Anticipated Run Date: ______ PAC Approved Days: ______

Spokesperson: JIANGUO ZHAO Hall Liaison: Will be available
Phone: (617) 258-5438
E-mail: JZHAO @ MITLNS.MIT.EDU

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)
	4045	100	No	^{3,4}He	930	415.
	1645	100	No.	^{3,4}He	930	170
	2445	100	No	^{3,4}He	930	125

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.