(A New Proposal to Jefferson Lab PAC22)

Study of Color Transparency in Two-Body Break-Up Processes

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Abstract

We propose an experiment for investigation of color transparency effects in nuclei by studying two-body break-up reactions at sufficiently large values of transverse momenta of the recoil nuclear system. Particularly we are interested in studies of the D(e,e'p)n, ^{3}He(e,e'p)d and ^{4}He(e,e'p)^{3}H reactions at Q^2 =1 to 7 $(GeV/c)^2$ range in transverse kinematics with recoil momenta $\geq 200\ MeV/c$.

The theoretical studies of the different groups demonstrate that the cross section of these reactions in these kinematics are dominated mainly by final state interaction (FSI) of knocked-out nucleon with the residual nuclear system. The measurement of this FSI at $Q^2 = 1$ to 7 $(GeV/c)^2$ range will allow to study the probability for the nucleon, struck by the electron, *to reinteract* at small internucleon distances of about 1 fm. As a result the expansion effect which most probably masks the color transparency effect in the A(e,e'p)X reactions will be significantly suppressed. This approach is complementary to more traditional studies of color transparency which have been focused on measuring the probability for the struck nucleon *not to interact*.

The appropriate observable in two-body break-up reactions would be the ratio of the cross sections defined in the kinematics dominated by FSI to the cross section of the same reactions measured at the kinematics dominated by Glauber screening effects. Conventional calculation predicts largely Q^2 independent ratio while the onset of color transparency results in the decrease of this ratio with increase of Q^2. The theoretical models of color transparency which agree with the recent data on transparency from A(e,e'p)X reactions predicts much larger effects in two-body break-up reactions which the proposed experiment should be able to detect. This proposed study will be able to answer the question whether the lack of the color transparency in A(e,e'p) reactions observed up to $Q^2 = 8$ $(GeV/c)^2$ is related to the large expansion effect or to the fact that no small size configurations are produced at these values of Q^2.

1 Introduction

1.1 Color Coherence Effects in QCD

The basic idea behind the prediction of color coherence effects in QCD is that the gluons emitted by a color-singlet object which is small-sized (or in a point-like configuration (PLC)) are canceled if the process is coherent. This is because, if the process is coherent, one computes the scattering amplitude by summing the terms caused by gluon emissions from different quarks. The implication is that for certain processes, the effects of initial and/or final state interactions will be absent. Realizing this idea in any specific experiment involves three key elements:

i) the weakness of the interaction of small color singlet objects at high energies; for example, a small $q\bar{q}$ dipole of transverse size r_t would experience an effective cross section $\sigma_{\text{eff}} \sim r_t^2$;

ii) the presence of configurations of small transverse size in hadrons;

iii) a large coherence length at high energies which leads to the possibility of considering the small-sized configurations as *frozen* during the collision.

The experimental accuracy also is a vital constraint in order to maintain the exclusive or nearly exclusive nature of the experiment, which is required for the necessary quantum interference effects to dominate the physics.

Color transparency (CT), as a prediction of pQCD, was observed in the E791 experiment at FNAL which investigated the exclusive coherent production of two jets in the process $\pi + A \to 2$ jets $+ A$ at $E_\pi = 500$ GeV. The observed A-dependence of the process[1, 2] is consistent with the predictions of [3], which lead to a seven times larger platinum/carbon ratio than soft physics would.

Evidence for color transparency effects was reported also in incoherent vector meson production in DIS scattering of muons [4]. Note that the HERA data on electroproduction of vector mesons convincingly demonstrated that the color diplole configuration in ρ mesons dominates already at $Q^2 \geq 5$ $(GeV/c)^2$ [5]. Hence we conclude that the general concepts of CT in pQCD regime are now firmly established, and can be used to address the question of its relevance in the intermediate energy range.

The special interest in color coherence studies is the observation of CT for the nucleon case, as in baryonic cases with color neutral qqq configurations which is unique to QCD. This is in contrast to the $q\bar{q}$ cases which represent the e^-e^+ analogue of charge neutrality in QED.

1.2 Challanges at Intermediate Energies

Two major questions should be addressed if color transparency is to be studied at intermediate energies:

- Can the PLC be treated as a frozen during the time that the projectile is passing through the nucleus?

- At what momentum transfer do effects of the PLC dominate in the elementary amplitude?

If the PLC is not frozen, it will *expand* and interact strongly as it moves through the nucleus. If the momentum transfer is not large enough for the PLC to dominate, then there will also be strong final state interactions.

To appreciate the problems we shall discuss the effects of expansion in a bit more detail. Current color transparency experiments are performed in kinematic regions where the expansion of the produced small system is very important. In other words the length (the coherence length l_c) over which the PLC can move without the effects of time evolution changing the character of the wave function is too small, and this strongly suppresses any effects of color transparency[6, 7].

The maximal distances of which coherence can be sustained for a given hadron h can be estimated using the uncertaintly principle: $l_c \sim \frac{2p_h}{\Delta M^2}$, in which ΔM is a characteristic excitation energy (for a small value of m_h one can write $\Delta M^2 = (m_{ex}^2 - m_h^2)/2$ where m_{ex}^2 is the invariant mass squared of the closest excited state with the additive quantum numbers of h). Numerical estimates show that, for the case of a nucleon ejectile, coherence is completely lost at distances $l_c \sim 0.3 - 0.5$ fm $\times\, p_h$, where p_h is measured in GeV/c [6, 7].

We next discuss the issue of the necessary momentum transfers required for PLC to be prominent. This can be studied by considering the applicability of perturbative QCD. Current analyses indicate that the leading twist approximation for the pion form factor could become applicable (optimistically) at $Q^2 \geq 10 - 20\ (GeV/c)^2$; see e.g. Ref. [9]. For the nucleon case even larger values of Q^2 may be necessary. However this does not preclude smaller than average configurations (including PLC's) from being relevant for smaller values of Q^2. For example large configurations with soft pions do not contribute to nucleon form factor at $Q^2 \geq 1 - 2\ (GeV/c)^2$[10].

In fact, in a wide range of models of the nucleon, such as constituent quark models with a singular (gluon exchange type) short-range interaction or pion cloud models, configurations of sizes substantially smaller than the average one dominate in the form factor at $Q^2 \geq 3-4$ GeV^2; see Ref. [11]. The message from the QCD sum rule model calculations of the nucleon form factor is more ambiguous.

1.3 Methods of Color Transparency Studies

The first step is to measure the nuclear transparency through the ratio:

$$T = \frac{\sigma^{Exp}}{\sigma^{PWIA}}, \tag{1}$$

where σ^{Exp} is the measured cross section and σ^{PWIA} is the calculated cross section using plane wave impulse approximation (PWIA) when no final state interaction is taken into account. The onset of color transparency will be observed if T grows and approaches unity with increasing energy transfer.

The first electron A(e,e'p) experiment looking for color transparency was NE-18 performed at SLAC [12]. The maximum Q^2 in this experiment is $\approx 7\ (GeV/c)^2$, which corresponds to $l_c \leq 2$ fm. For these kinematics, color transparency models which included expansion effects predicted a rather small increase of the transparency; see for example [14]. This prediction is consistent with the NE-18 data. However these data are not sufficiently accurate either to confirm or to rule out color transparency on the level predicted by realistic color transparency models. A recent Jlab experiment[13] has been performed up to $Q^2 = 8\ (GeV/c)^2$, and no effects of color transparency have been observed. However, models of color transparency which predict noticeable effects of color transparency in the A(p,pp)X reaction at BNL [15] include versions which can also lead to almost no effects in electron scattering for the kinematics of [13]. In those models, for A(p,pp)X reactions, the effects of expansion are strong for the lower energy final state wave functions, but do allow some color transparency to occur for the initial state wave function. At $Q^2 = 8\ (GeV/c)^2$, the energy of the proton ejected in electron scattering is about 4 GeV, which is still smaller than the 6 GeV of the BNL experiment. One needs to achieve a Q^2 of about 12 $(GeV/c)^2$ to obtain a contradiction between the electron scattering and proton scattering experiments. Figure 1 demonstrates the existing experimental and theoretical situation in studies of CT at $A(e,e'p)X$ reaction.

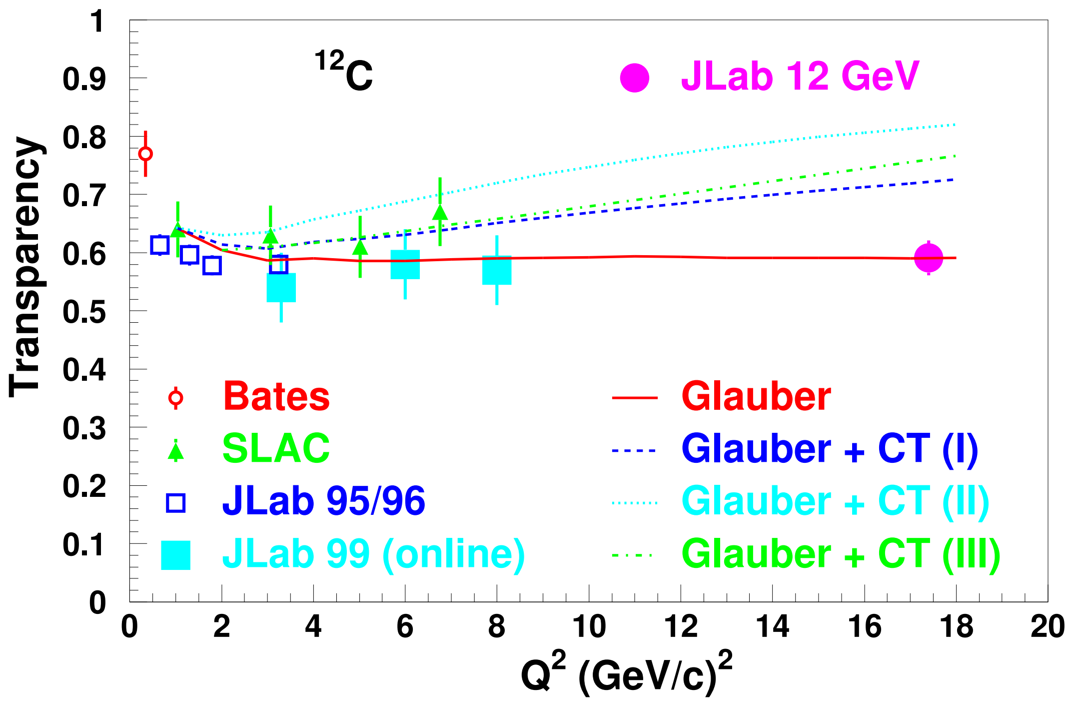

Figure 1: The Q^2 dependence of $T = \frac{\sigma^{Exp}}{\sigma^{PWIA}}$ for $^{12}C(e,e'p)$. "Glauber" - calculation within Glauber approximation, "Glauber+CT(I) and Glauber+CT(II)" - calculations including CT effects with expansion parameter $\Delta M^2 = 1.1\ GeV^2$ and $\Delta M^2 = 0.7\ GeV^2$ respectively[16], "Glauber+CT(III)" - CT effects are included according to Ref.[17].

To obtain a more detailed knowledge of the interaction of PLC with nuclei it is possible to identify processes in which the ejectile should neccessarily reinteract during its passage through the nucleus [18, 19, 20, 21]. This can be done by studying high Q^2 (e,e'p) reactions with nuclear recoil system (consisting of one or few nucleons) produced with transverse momenta $p_t \geq 200$ MeV/c. The cross section of the production of such recoil states should decrease substantially with the onset of CT. An important advantage of these reactions is that the effect of the disappearance of the final state interaction can be studied using the lightest nuclei (D,^{3}He,^{4}He), for which wave functions are known much better and the eikonal approximation which accounts for all orders of rescattering[19, 20, 21] can provide a reliable base line calculation. Another advantage is that the inter-nucleon distances probed are not large, 1-2 fm. These distances are comparable to the coherence length for values of Q^2 as low as about 4-6 (GeV/c)^2, and may provide evidence for a number of color coherent phenomena in the intermediate Q^2 region.

1.4 Two-Body Break-Up Processes

The two-body break up reactions in the kinematics where recoil hadronic sytem is produced with the large transverse momenta ($p_t \geq 200\ MeV/c$) are ideal candidates for CT studies since the reaction is dominated by final state interactions. These reactions are

$$e + D \to e' + p + n \tag{2}$$

$$e +^3 He \to e' + p + d \tag{3}$$

$$e +^4 He \to e' + p +^3 H, \tag{4}$$

where one chooses a kinematics in which the proton carries almost whole energy and momentum of virtual photon while the recoil system has a momenta $p_r \geq 200\ MeV/c$.

The theoretical studies of these reactions (see e.g. [20, 22, 23, 24, 26] demonstrated that at the kinematics in which the recoil momenta is almost transverse to $\vec{q}$, the cross section is dominated mainly by the final state rescatterings. Figure 2 and 3 demonstrates this for the reactions (2) and (4) respectively.

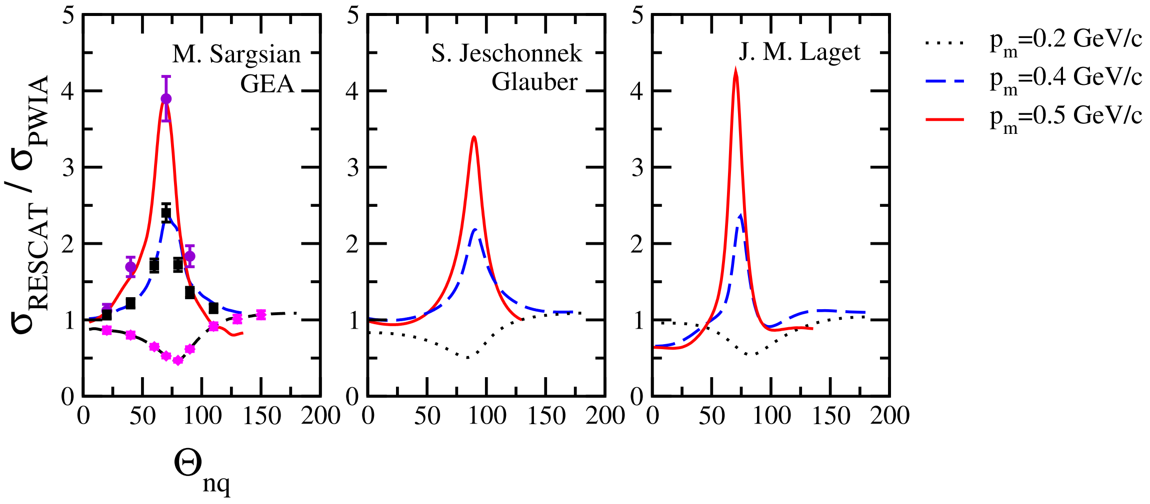

Figure 2: The ratio between the D(e,e′p) full (PWIA+FSI) cross section to the PWIA cross section, calculated at 4 GeV^2 according to different models.

The theoretical calculations in Figure 2 is done within the Generalized Eikonal approximation (GEA) of [24]. Very similar results are obtained within Eikonal approximation of Laget[21] or another approach from Jeshonnek [25].

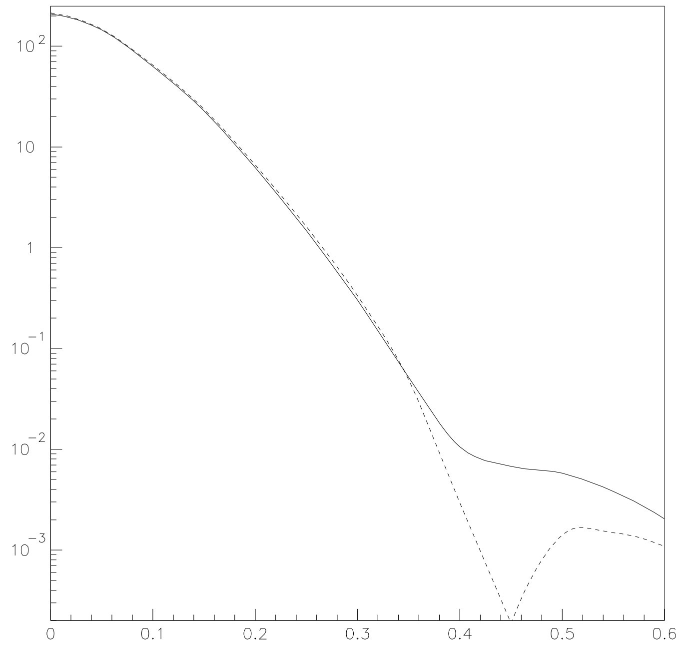

Figure 3: The p_m dependence of the ^{4}he(e,e'p)t cross section at $\theta_m = 90^0$. The solid line is the Full calculation , the dotted line is the PWIA calculation.

For reaction (4) Figure 3 demonstrates that at $p_r \approx 420\ MeV/c$ the whole cross section is defined by FSI [26]. Similar results are predicted within Glauber approximation in Refs. [22, 23]. Note that these results are consistent with the results from low energies, in which the theoretical calculations[27, 28, 29] and the data [30] for the reaction (4) demonstrated that the cross section at transverse kinematics is determined mainly by FSI and Meson Exchange contributions.

1.5 Observables

Having established the reactions and kinematics in which the cross sections are determined mainly by FSI, next we should identify the observables which have a weak Q^2 dependence in the framework of eikonal approximation. The later should be confronted with the CT prediction which results in a stronger energy dependence.

The appropriate measure for color transparency in two-body break-up reactions is a ratio of cross sections, measured at kinematics for which the multiple rescatterings are dominant, to the cross section measured at kinematics where the effect of the Glauber screening of impulse approximation is more important.

Specifically we consider the example for $e + D \to e' + p + n$ reaction. At $Q^2 > 1\ (GeV/c)^2$ the main contributions come from the impulse approximation, A_0^μ (Fig.(4(a))) and the rescattering, A_1^μ (Fig.(4(b))) amplitudes. As a result the cross section will depend on three terms: PWIA ($\sim |A_0^\mu|^2$), interference, ($\sim 2Re|A_0^\mu A_1^\mu|$) and rescattering, ($\sim |A_0^\mu|^2$). At $Q^2 \geq 1\ (GeV/c)^2$ the intereference term is negative and referred as a Glauber screening term. As Figure 2 demonstrates one can clearly separate kinematics, in which Glauber screening is dominant ($\theta_{nq} \approx 90^0$ and $p_m \approx\ 200\ MeV/c$) from kinematics, in which the rescattering is dominant ($\theta_{nq} \approx 90^0, p_m \geq 400\ MeV/c$).

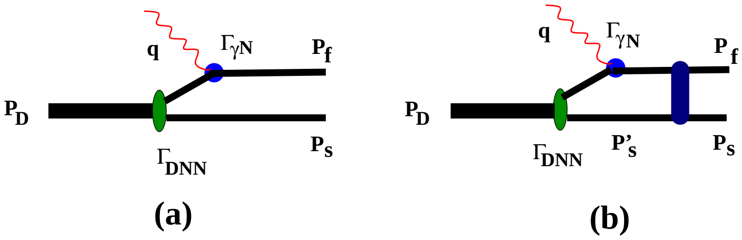

Figure 4: Diagrams corresponding to impulse approximation (a) and rescattering (b) contribution in $e+D \to e' + p + n$ reaction.

Theoretical investigations of the class of the two-body reactions for D, ^{3}He and ^{4}He nuclei[19, 20, 22, 23, 26, 27] demonstrated that it is always possible to separate these two kinematic regions by choosing two momentum intervals for the recoil nucleon, (300–500 MeV/c) for double scattering and (0–200 MeV/c) for Glauber screening.

Thus the suggested experiment will measure the Q^2 dependence of the following ratio:

$$R = \frac{\sigma(p = 400\ MeV/c)}{\sigma(p = 200\ MeVc)} \tag{5}$$

for reactions (2), (3) and (4).

In figures 8 and 9 the upper solid lines represent the predictions of GEA for ratio (5). This is compared with the shaded regions which show the predictions which include the color transparency effects. The bottom solid lines are the ratios for PWIA calculations.

In all cases the color transparency effects are estimated within quantum diffusion model (QDM) of Ref. [6] utilizing two values for the expansion parameter $\Delta M^2 = 0.7$ and $1.1\ GeV^2$, which characterize the time development of the PLC during the propagation in the nuclear medium. These two values of ΔM^2 give the upper and lower limit of CT predictions within QDM model. The time development of the PLC can also be obtained by modeling the ejectile-nucleus interaction using a baryonic basis for the PLC [7, 8, 17]. However numerically both QDM and the baryonic basis models predict similar values for the CT effects (see e.g. [20]). Thus our estimates are made only with QDM predictions.

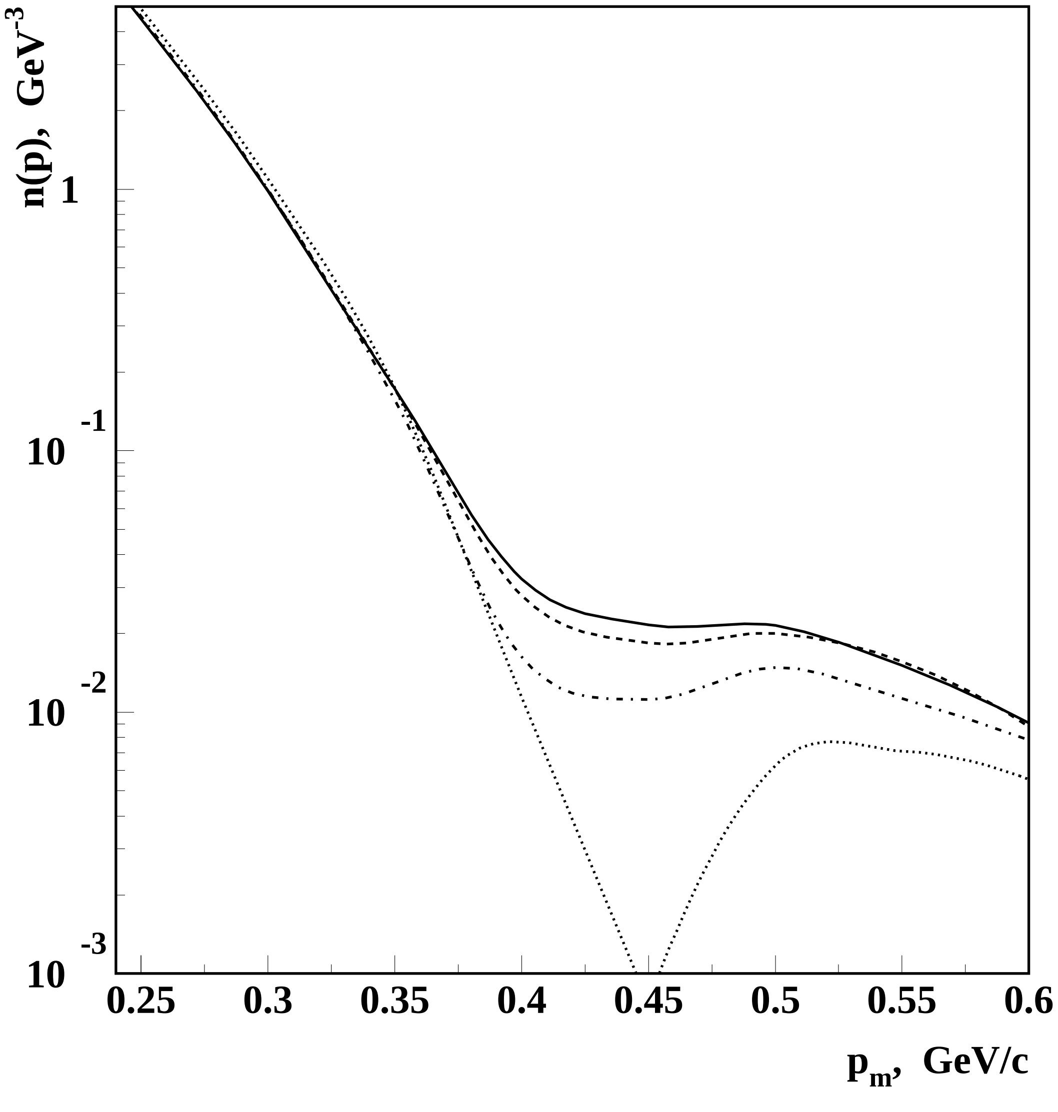

Figure 5: The momentum dependence of normalized cross section of $^4He(e,e'p)^3H$ *reaction. The dotted line is PWIA prediction. Solid line - Glauber prediction at* $Q^2 = 4\ (GeV/c)^2$*. The dashed and dot-dashed lines are CT prediction for* $Q^2 = 4$ *and 7* $(GeV/c)^2$ *respectively. The CT effects are calculated within quantum diffusion model of Ref.[6].*

2 Relation to Other Jefferson Lab Proposals

2.1 Hall C Experiment 94139

This experiment aimed at looking for color transparency in (e,e′p) reactions on various nuclei. The maximum Q^2 was ~ 8 (GeV/c)^2 [13]. Since the data covered the full p_{miss} region (0-300 MeV/c) for each Q^2, it was dominated by the very low p_{miss} region and therefore by single (PWIA) scattering. In this context, the data are consistent with calculations that do not include color transparency effects, but are not sufficiently accurate or at high enough Q^2 to rule out color transparency at the level predicted by several realistic CT models [14].

2.2 Hall B Experiment 94019

A complementary experiment E94-019 has already run in Hall B during the e6 run period in February–March 2002, and the data analysis is currently in progress. E94-019 is a search for color transparency using the reaction D(e,e′p_s), in which the electron quasi-elastically scatters from the neutron in the deuteron, and the recoiling spectator proton is detected with CLAS. The integrated luminosity ($\sim$15,000 pb$^-$1) for this experiment at 5.7 GeV beam energy is sufficient to map out the e′$\mathrm{p_s}$ cross sections over a wide kinematic range of spectator proton momenta (> 200 MeV/c) and Q^2 (1-6 GeV^2). The intent is to understand the enhancement of the spectator proton momenta due to n-p collisions (FSI's) at low Q^2 where conventional nuclear physics models are expected to do well. This is most obvious in the ratio R $= \sigma(\mathrm{p_s} =$ 400Mev/c$)/\sigma(\mathrm{p_s} =$ 200Mev/c) for quasi-elastic events, in which the numerator is enhanced by FSI's and the denominator is suppressed by the interference of the FSI and Born amplitudes. A significant deviation in the evolution of R with Q^2 from the conventional models is the signature for color transparency. At $Q^2 = 6$ (GeV)^2, the expected statistical accuracy of the data should distinguish between conventional FSI's and realistic color transparency calculations.

The present proposal in Hall A is complementary to the Hall B experiment e94019. It directly measures the struck proton from all 3 nuclei (D, ^{3}He, ^{4}He) as opposed to measuring the recoiling spectator proton and inferring the scattering of the neutron within the deuteron. This direct experimental method is expected to be much more sensitive than the spectator proton method. In the case of the Helium nuclei, the struck proton will again be detected as opposed to measuring the recoiling spectator protons in the (e,e′pp) reaction in the CLAS, with all the added phase space uncertainties. Moreover, the Hall B experiment chooses kinematics where the recoil system is intergrated over the whole range of the excitation energies. As a result the final hadronic system is dominated mainly by 3-body break-up configuration, which is significanly less sensitive to the FSI than the 2-body break-up configurations. The resolution of the Hall A spectrometers allow to separate the 2-body from the 3-body breakup channels in the residual nuclei, thus making the interpretation of the results less ambiguous.

3 Experimental Setup

3.1 Equipment

Hall A has proven itself capable of extracting high quality cross sections and response function [31, 32]. In fact, these results from the reaction ^{16}O(e,e'p) came from the first experiment to be performed in Hall A and since then the knowledge of the spectrometers has been constantly improving. Presently, the analysis of the ^{2}H(e,e'p) [33] and ^{3}He(e,e'p) [36] experiments are underway and there is an approved experiment to measure accurate cross sections and extracting the response functions from the ^{4}He(e,e'p) [37] reaction.

We plan to measure the reaction (e,e'p) in ^{2}H, ^{3}He and ^{4}He, by making use of the techniques developed from these experiments, the Hall A high resolution spectrometers, and the cryogenic LD2 and high pressure ^{3,4}He targets. At least two of these targets can be used simultaneously, thus minimizing the times to change targets. With a missing energy resolution of 1 Mev, the two-body peaks in the ^{3}He (e,e'p)d and ^{4}He (e,e'p)t will be well separated from the two-, three- and four-body break-up continuum in the residual nuclei.

Cross sections, count rate calculations and simulations for the proposed measurements were estimated using a beam current of 100 uA on a 10 cm long LD2 cryogenic target with a density of 0.17 gm/cm3. This translates to a target luminosity of 3 x $10^{38} cm^{-2} sec^{-1}$ for the deuterium. For ^{3}He and ^{4}He, a 10cm long target with densities of 0.06 and 0.14 gm/cm3 respectively will be used. These targets can handle beam currents up to 120 uA, which translates to target luminosities in excess of 1 x $10^{38} cm^{-2} sec^{-1}$. We have assumed a luminosity of 1 x $10^{38} cm^{-2} sec^{-1}$ for both the He targets, though we are sure that in the case of ^{4}He, the achievable luminosity could easily be double this number. A 20 cm long "beer can" He cryotarget is presently under construction which would essentially double the proposed target luminosities for the Helium targets. It would also have the added benefit of reducing the multiple scattering of the ejected particles, thus resulting in a better missing energy resolution.

The standard properties of the Hall A spectrometers were used in making the count rate estimates - solid angles of 5 msr and momentum bites of +/- 4.5%. In making our count rate estimates, we used the PWIA spectral functions (reduced cross sections) of Arenhovel for ^{2}H and Laget for ^{3}He. This is the most conservative estimate for the rates and is applicable only when full color transparency has set in. In general the rates would be larger than these estimates.

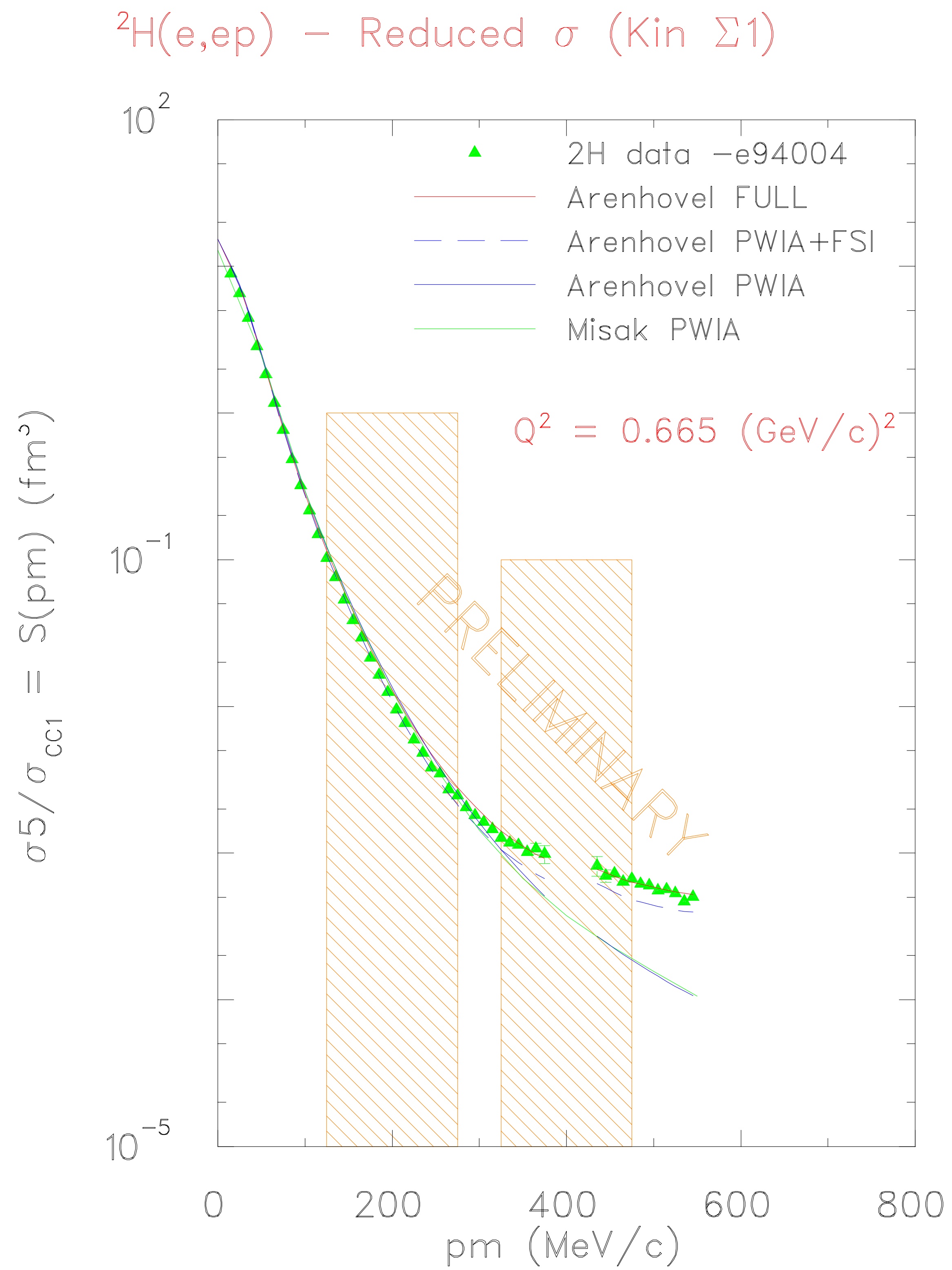

Figure 6: The reduced cross section for ^{2}H(e,e'p)n. The data are from [33]. The calculations are from [34] and [35].

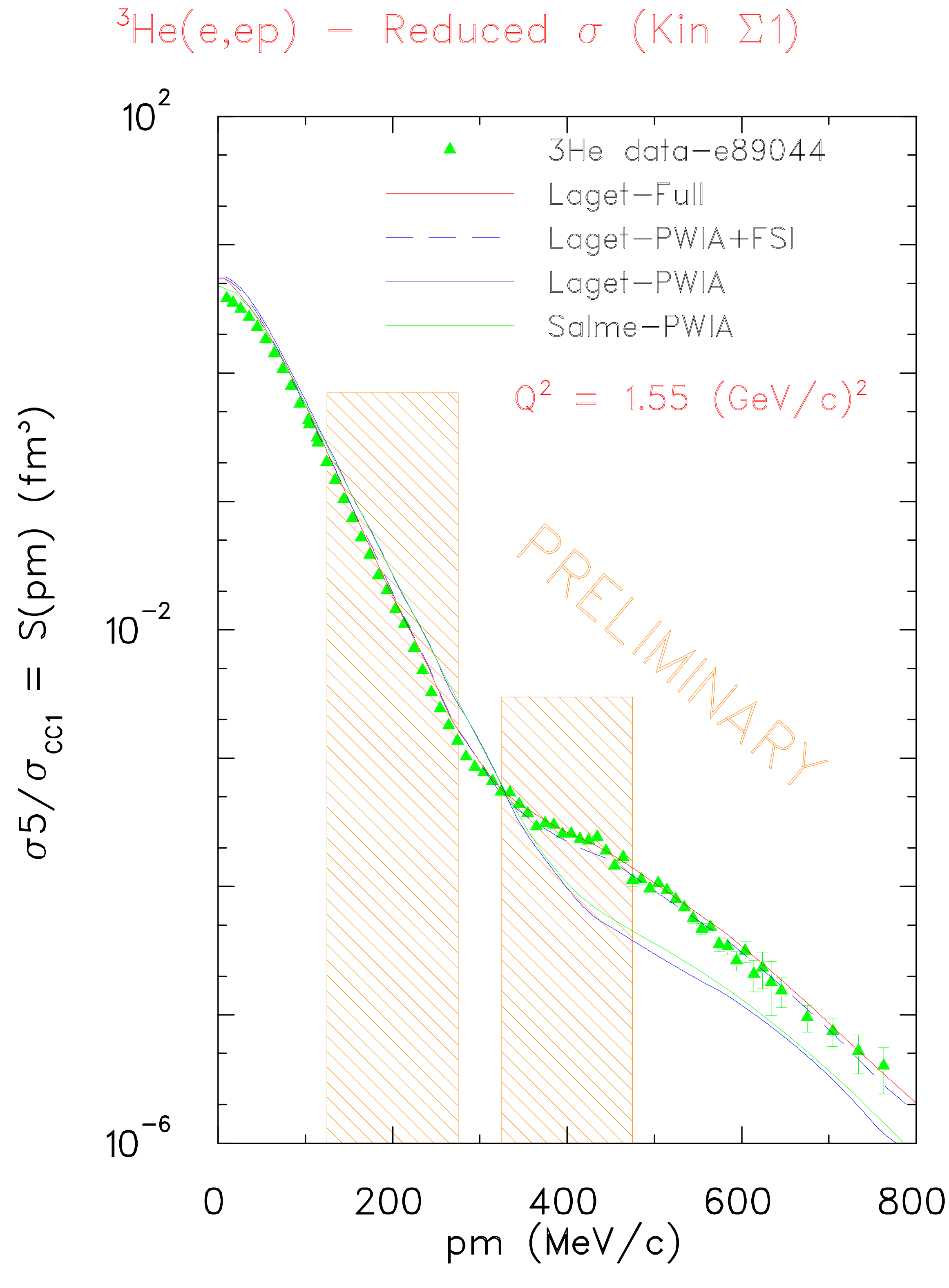

Figure 7: The reduced cross section for ^{3}He(e,e'p)d. The data are from [36]. The calculations are from [27].

3.2 Kinematics

We shall make the measurements in quasielastic (x $\sim$1), constant (q, ω) kinematics (sometimes referred to as "perpendicular" kinematics). To make the measurements at $p_{recoil} = 200$ and 400 MeV/c, we shall just change the hadron angle, keeping all other kinematic variables constant (see Tables 1 and 2). We wish to make the measurements with the highest available beam energy presently available (5.7 GeV). In this case, two different beam energies (4.57 and 5.7 GeV) are necessary for the measurements, but the two energies only require a different pass beam to be sent to Hall A (4- and 5-pass beams respectively). For the two highest Q^2 values (at 5.25 and 6.5 $(GeV/c)^2$), we will have to interchange the left and right spectrometers for hadron and electron detection respectively, as the maximum momentum in the right HRS is limited to about 3.1 (GeV/c).

3.3 Singles rates

The single-arm background rates were calculated with the computer codes QFS for the (e,e') rates and the EPC code for the (e,p), (e,π^+), and (e,π^-) rates. In all cases the singles rates are very manageable ($\leq$ 5 kHz for the (e,e') rates and $\leq$ 1 kHz for the hadron rates) for all kinematics except the lowest Q^2 point (=1 $(GeV/c)^2$) where we can easily lower the luminosity and still obtain the necessary true coincident counts in less than an hour. As demonstrated during the (e,e'p) experiments on D, ^{3}He and ^{4}He, which have made measurements at the lower Q^2 points as this proposal (between 1 and 2 $(GeV/c)^2$), rates such as these are not a problem for the Hall A spectrometers.

3.4 Coincidence rates

We determined the coincidence rates by assuming a luminosity of 3 x $10^{38} cm^{-2} sec^{-1}$ for deuterium and 1 x $10^{38} cm^{-2} sec^{-1}$ for the Helium targets. A missing energy width of 1.6 MeV and a timing width of 2 ns was used to determine the true and accidental rates. The computer code SEEX [38] was used in computing the fivefold differential cross sections at each kinematic point, as well as the true and accidental rates. In all cases the true to accidental (S/N) rate is a factor 1000 or better. The accidental rates were determined from the single (e,e') and (e,p) cross sections described earlier.

3.5 Systematic and Statistical Uncertainties

With careful luminosity monitoring and appropriate normalisation measurements we should be able to achieve a systematic uncertainty of $\sim$2% as exhibited in the (e,e'p) experiment on 3He [36]. We have therefore assumed a systematic uncertainty of 2% for all our cross section measurements. Since the only change in the measurement of the ratio $R = \sigma(p = 400 MeV/c)/\sigma(p = 200 MeV/c)$ is just the angle of the hadron arm (all the electron arm parameters, the hadron arm momenta and the beam energy etc... remain constant during the measurement of the ratio) the systematic error is small ($\leq$ 1%) and the main uncertainty in the determination of the ratio R is just the statistical uncertainty for the high Q^2 points. In all kinematics, we obtain $\leq$ 5% statistics except at the very highest Q^2 value for ^{3}He, where we get 10% statistics.

4 Expected Results

A suitable measure of this effect can be studied in the (e,e'p) reaction as a ratio R of the cross section in kinematics where the rescattering term is dominant ($p_{recoil} \sim 400\ MeV/c$) to the cross section in kinematics where single scattering is dominant ($p_{recoil} \leq 200\ MeV/c$) and Glauber screening is important. Figure 6 and 7 shows these regions clearly in the recent ^{2}H(e,e'p)d [33] and ^{3}He(e,e'p)d [36] reaction cross section as a function of the missing momentum for a low values of $Q^2(\sim 1(GeV/c)^2)$. In Table 1 and 2 , we show the kinematics and the estimated running times in studying the ^{2}H(e,e'p)n and ^{3}He(e,e'p)d reactions with the two Hall A High resolution Spectrometers up to Q^2 values of $\sim 6.5(GeV/c)^2$. We assume similar rates for ^{4}He(e,e'p)t as in the ^{3}He(e,e'p) case. In Figures 8 and 9 we see the predicted value of this ratio $R = \sigma(p = 400\ MeV/c)/\sigma(p = 200\ MeV/c)$ for the case of D(e,e'p)n and ^{4}He(e,e'p)t[[35],[6]] and the effect of color transparency is quite dramatic even at low values of Q^2. With our uncertainties, we should be able to see this effect.

Table 1: Kinematics and Run Time Estimate for $R = \sigma(p = 400\ MeV/c)/\sigma(p = 200\ MeV/c)$ for $^2H(e,e'p)d$ reaction. The total estimated running time is $\sim$ 65 hours for a $\leq 5\%$ uncertainty in the ratio R for all Q^2 points.

Q^2	E_i	E_f	θ_e	$p(=q)$	$p_R = 200MeV/c$			$p_R = 400MeV/c$			Total
$(GeV/c)^2$	GeV	GeV	deg	GeV	θ_p deg	cts/hr	Time	θ_p deg	cts/hr	Time	hours
1.0	4.57	4.037	13.37	1.112	65.63	5.5e5	1	76.13	1.7e4	1	2
2.0	4.57	3.504	20.36	1.753	49.98	6.6e4	1	56.55	2310	1	2
3.0	5.7	4.101	20.64	2.340	42.69	2.6e4	1	47.59	920	1	2
4.0	5.7	3.568	25.62	2.906	35.78	7670	1	39.72	275	2	3
5.25	5.7	2.902	32.72	3.165	28.88	1790	1	32.05	65	8	9
6.5	5.7	2.236	41.84	4.284	22.95	370	4	25.61	13	40	44

Table 2: Kinematics and Run Time Estimate for $R = \sigma(p = 400\ MeV/c)/\sigma(p = 200\ MeV/c)$ for $^3He(e,e'p)d$ reaction. The total estimated running time is $\sim$ 180 hours for a $\leq 5\%$ uncertainty in the ratio R for all Q^2 points except the last two where the uncertainty is $\leq 10\%$.

Q^2	E_i	E_f	θ_e	$p(=q)$	$p_R = 200MeV/c$			$p_R = 400MeV/c$			Total
$(GeV/c)^2$	GeV	GeV	deg	GeV	θ_p deg	cts/hr	Time	θ_p deg	cts/hr	Time	hours
1.0	4.57	4.037	13.37	1.112	65.63	3.7e5	1	76.13	1600	1	2
2.0	4.57	3.504	20.36	1.753	49.98	4.4e4	1	56.55	200	2	3
3.0	5.7	4.101	20.64	2.340	42.69	1.7e4	1	47.59	76	6	7
4.0	5.7	3.568	25.62	2.906	35.78	5060	1	39.72	23	21	22
5.25	5.7	2.902	32.72	3.600	28.88	1170	2	32.05	5	40	42
6.5	5.7	2.236	41.84	4.284	22.95	241	2	25.61	1	100	102

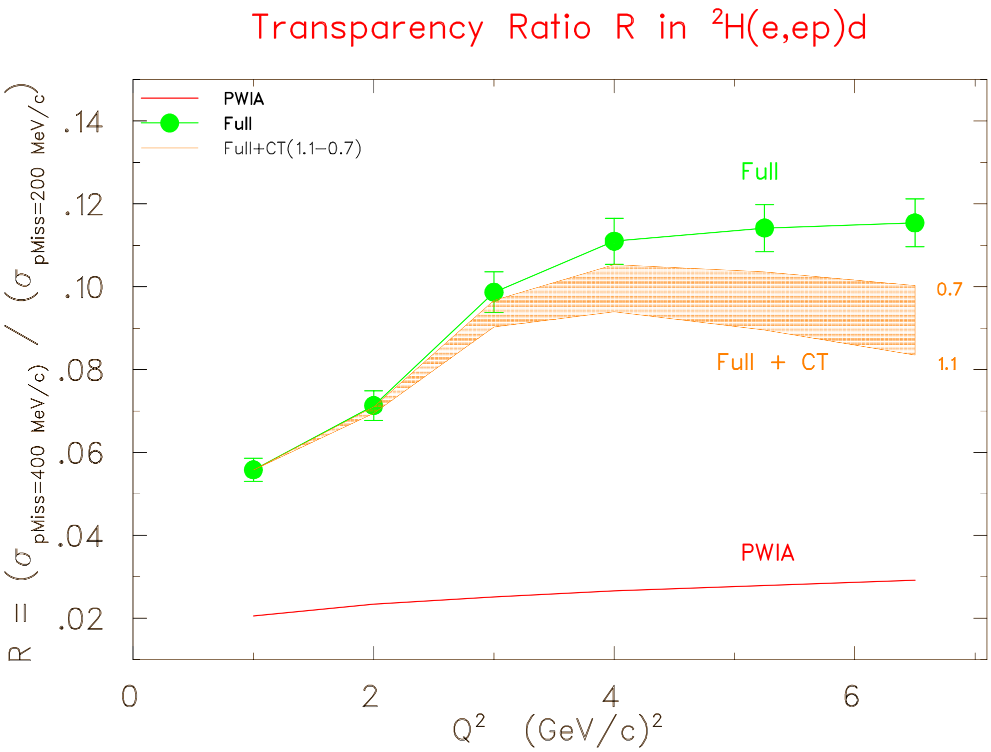

Figure 8: Transparency Ratio R for ^{2}H(e,e'p)n. The calculations are from Sargsian [35]. The projected experimental uncertainties are denoted by the error bars.

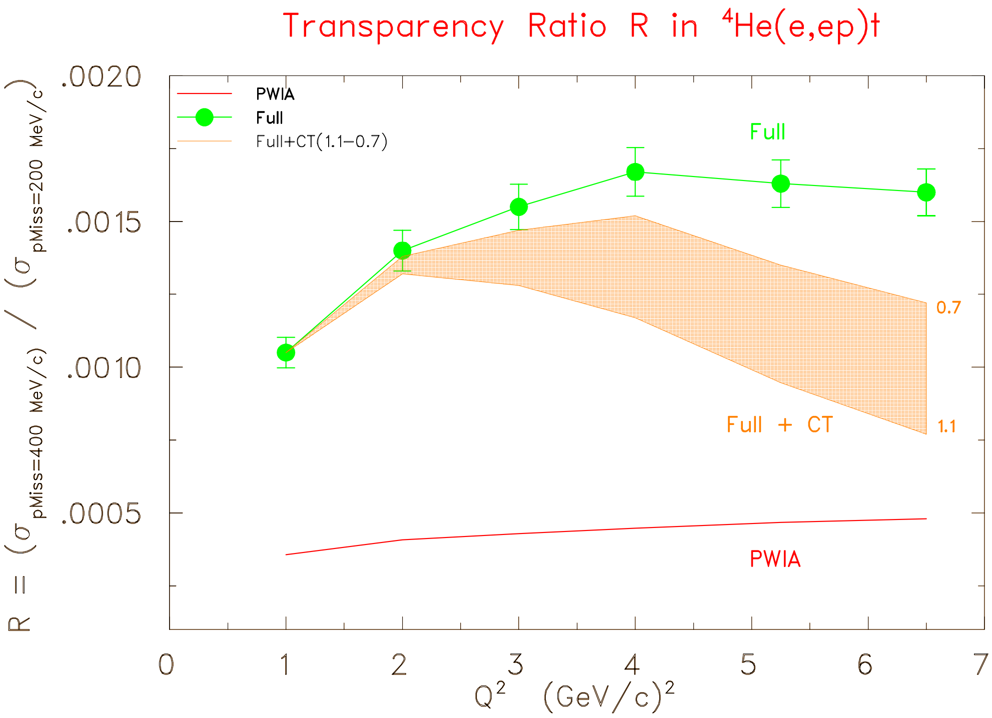

Figure 9: Transparency Ratio R for ^{4}He(e,e'p)t. The calculations are from Sargsian [35]. The projected experimental uncertainties are denoted by the error bars.

5 Beamtime Request

To perform this experiment and make the necessary systematic measurements, we request 20 days of beamtime, as shown in Table3. The table shows all necessary time, including the time to move the spectrometers. The two different energies needed by this experiment only require a different pass beam to be sent to Hall A. For the two highest Q^2 values (at 5.25 and 6.5 $(GeV/c)^2$), we will have to interchange the left and right spectrometers for hadron and electron detection respectively, as the maximum momentum in the right HRS is limited to about 3.1 (GeV/c).

Table 3: Time requested for the ^{4}He(e,e'p)^{3}H response function seperation experiment.

$^2H(e,e'p)$	65 hrs
$^3He(e,e'p)$	180 hrs
$^4He(e,e'p)$	180 hrs
Angle and Momenta Changes	25 hrs
Calibrations and Normalizations	30 hrs
Total	480 hrs (20 days)

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