Measuring the EMC Effect with tagged high momentum recoil nucleons

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Introduction

We propose to measure semi-inclusive deep inelastic scattering (DIS) off ^{4}He and the deuteron by "tagging" the DIS scattering with high momentum recoiling protons and neutrons emitted at large angle relative to the momentum transfer. Assuming that in the reaction $\mathrm{A}(e,e'N_s)$ the backward recoiling nucleon is a spectator to the DIS off a short-range correlated partner nucleon, this measurement can be used to study scattering from high-momentum (off shell) nucleons. This proposed measurement can have important implications for the explanation of the EMC effect and its relation to Short Range Correlations (SRC).

We will focus on two experimental signatures: 1) the doubly-tagged EMC ratio of the per-nucleon tagged cross section in ^{4}He relative to the same in *d* as a function of Bjorken *x* and 2) the singly-tagged EMC ratio, the ratio of the per-nucleon tagged ^{4}He cross section to the untagged *d* cross section. In both cases we will integrate over a very wide range of backward-recoiling nucleons.

The electrons will be detected in Hall C by both the SHMS and HMS, simultaneously covering two regions in *x*. The recoiling protons and neutrons will be detected by a backward Large Acceptance Detector (LAD) covering scattering angles from about 85^o to 175^o. The LAD will use about 130 scintillator detectors from CLAS that are not needed for CLAS12. This LOI complements a proposal submitted to PAC38 to measure semi-inclusive DIS off the deuteron.

The EMC Effect and Short Range Correlations

A recent paper [1] found that the size of the EMC effect [2,3] in a given nucleus is closely correlated with the probability for a nucleon in that nucleus to belong to a *2N*-SRC pair (see Fig. 1). These pairs are characterized by a large relative momentum and small center-of-mass momentum, where large and small are relative to k_F, the Fermi momentum of heavy nuclei [4-20]. This strongly suggests that the EMC effect is due to high momentum nucleons in nuclei. Since almost all high-momentum nucleons in nuclei belong to SRC nucleon pairs, when we detect a high-momentum nucleon recoiling backwards with respect to the momentum transfer, we can be reasonably confident that the electron scattered from its high-momentum correlated partner. In this way we can select the events where DIS scattering occurred on a high-momentum nucleon.

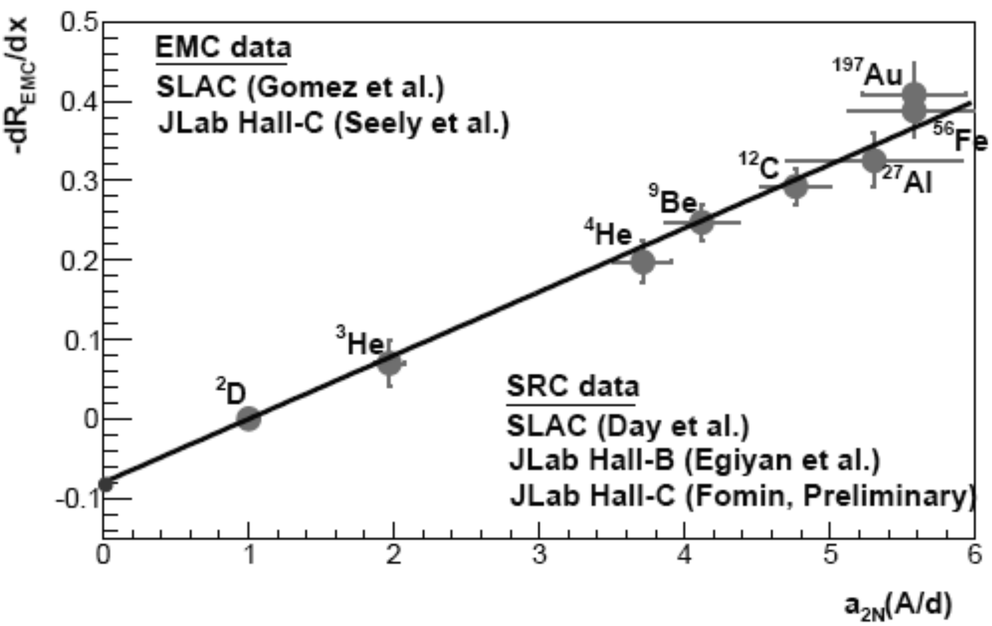

Figure 1: The negative of the EMC slope plotted vs. the relative probability that a nucleon belongs to an *NN* SRC pair for a variety of nuclei (see details in [1]).

If the EMC effect is predominantly associated with 2N-SRC pairs in nuclei, then the per-nucleon ratio of the tagged DIS cross sections for *d* and nucleus *A* (the "tagged" EMC ratio) should be almost independent of *x* and larger than unity. This is because, in both nuclei, the spectator backward nucleon tags the reaction so that the electron is scattering from a high momentum forward-going nucleon. Thus, the electron is scattering from nucleons with the same momenta and virtuality in both nuclei. If the EMC effect depends on the virtuality of the struck nucleon rather than on the nuclear density, the per-nucleon cross section ratio (the EMC ratio) of the two nuclei should be independent of *x*. The magnitude of the ratio should equal the relative probabilities for a nucleon to belong to a SRC pair in those two nuclei.

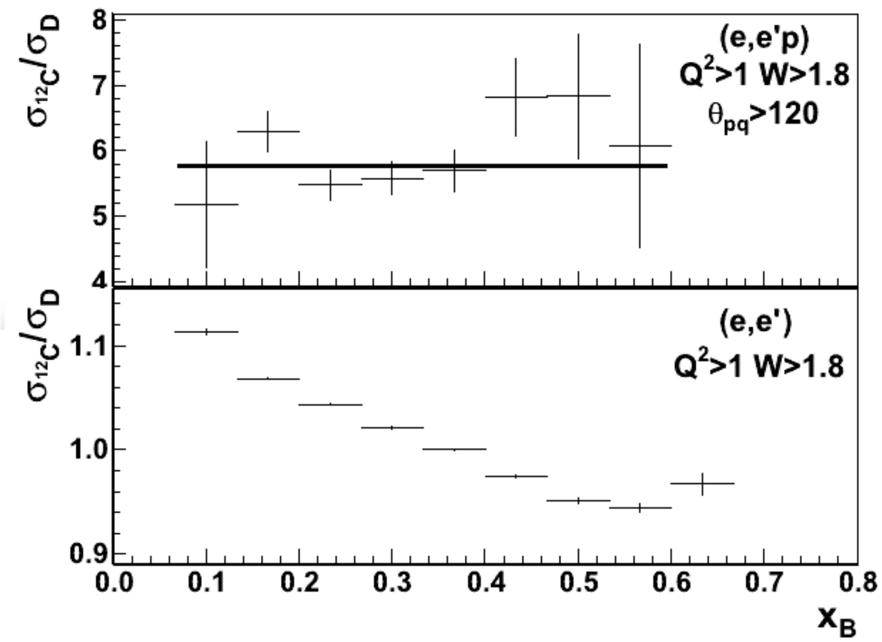

Figure 2: Preliminary and not for release. The per-nucleon DIS cross section in ^{12}C divided by the same quantity for the deuteron. Bottom: untagged inclusive cross section; top: the cross section tagged by a high momentum, $p > 0.3$ GeV/c, backward proton. The data are a preliminary analysis of CLAS data by O. Hen, as a part of the CLAS data mining project.

Fig. 2 shows a very preliminary analysis of CLAS eg2 data. In this experiment, 5 GeV electrons were incident on a deuterium and a solid target simultaneously. [Note that the data are not corrected for final state interactions, radiative effects, acceptance effects, etc. Note that we allow Q^2 values as low as 1 GeV^2 in order to increase statistics. However, higher twist effects should cancel in the EMC ratio.] The bottom plot shows the EMC ratio of the per-nucleon DIS (e, e') cross sections for C and deuterium. It shows the typical linear decrease in the ratio from $x = 0.3$ to $x = 0.6$. The top plot shows the tagged EMC ratio, requiring that a high momentum proton ($p > 0.3$ GeV/c) be detected at an angle greater than 120 degrees from the momentum transfer. Although the statistics are marginal, the results are consistent with being constant with x and the value of the ratio is about 6, slightly larger than the expected ratio of $a_{2N}(\text{C}/d) = 4.8 \pm 0.4$.

While it would be premature to draw quantitative conclusions from this preliminary data, the tagged EMC ratio is clearly very different from the untagged data and agrees with our simple idea that the EMC effect is predominantly related to DIS from high-momentum nucleons that are partners in SRC pairs.

The Proposed Measurement

We propose to measure the singly and doubly tagged EMC ratios of ^{4}He to d. As shown above, the doubly tagged EMC ratio will be the per-nucleon cross section ratio of $^4\text{He}(e, e' N_s)$ integrated over all nucleon momenta $p_s > 0.275$ GeV/c (onset of the scaling [9,10]) and angles

$\theta_{ps} > 110^o$ divided by the same for deuterium. To ensure DIS we will select events with Q^2>2 GeV/c^2 and W> 2 GeV/c^2. The singly tagged EMC ratio will be the per-nucleon cross section ratio of ${}^4\mathrm{He}(e,e'N_s)$ integrated over all nucleon momenta $p_s > 0.275$ GeV/c and angles $\theta_{ps} > 110^o$ divided by the inclusive $d(e,e')$ cross section. Both of these will be measured as a function of $x = Q^2/2m\omega$.

Since high momentum nucleons comprise approximately 20% of ^{4}He, if the EMC effect depends on nucleon virtuality then the *x*-dependence of the singly-tagged EMC ratio should be about five times larger than that of the standard (untagged) EMC effect. On the other hand, if the EMC effect depends on density then the *x*-dependence of the singly-tagged EMC effect should be the same as the standard EMC effect. This effect should be significantly larger than the effects of FSI.

In the doubly-tagged ^{4}He/*d* ratio many of the FSI effects are expected to cancel out. We will test some of these effects by varying the nucleon angle and momentum integration regions.

The Experimental setup

We propose to perform the measurement in Hall C using the two high-resolution spectrometers (SHMS and HMS) in coincidence with a dedicated scattering chamber and a large-angle proton and neutron detector: LAD. See the proposal "In Medium Nucleon Structure Functions, SRC, and the EMC Effect" submitted to PAC38 for more details.

LAD - the recoil nucleon detector

To detect recoil nucleons, we propose to use a Large Acceptance Detector (LAD). In order to save money and effort, this detector will be assembled from the scintillator counters (TOF) of the current CLAS (CLAS6) that will not be used as part of CLAS12. We propose to use all 6 sectors of panels 3 and 4 of the TOF system, amounting to 138 scintillators.

Using these detectors for the LAD requires that they be removed intact when CLAS6 is decommissioned. A decision to save these detectors must be taken before decommissioning starts in May 2012.

For this measurement, we plan to cover scattering angles from 85 to 174^o on the beam-left side at a distance of about 4 meters from the target. See Figure 3. The approximately 4-m long scintillator bars will then give an out-of-plane angular coverage of about $\pm 25^o$ (less from about 85 to 112^o where the SHMS structure reduces the acceptance to about $\pm 10^o$). We propose to stack two thicknesses of the TOF counters at smaller angles (85 to 112^o), and five thicknesses at larger angles (111 to 174^o). This will give a total solid angle of about 1.5 sr and a neutron detection efficiency of about 20% at the larger angles. Note that the LAD is very flexible and its optimized final configuration will differ slightly from that presented here.

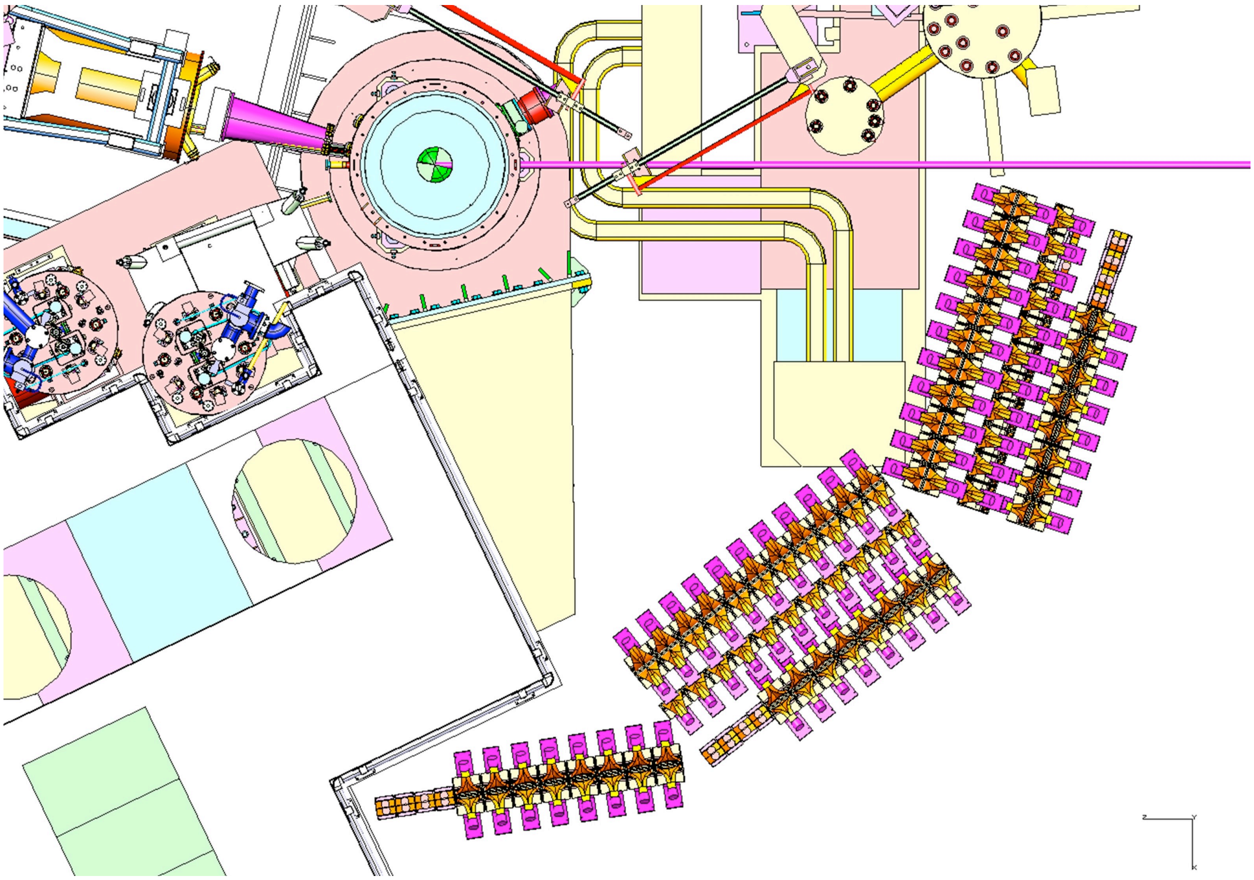

Figure 3: Plan view of the layout of the LAD detector in Hall C. The incoming beam line is shown by the purple horizontal line in the upper left. The scattering chamber is shown by the light blue circle in the middle toward the top of the figure. The HMS entrance is shown in the upper left and the SHMS structure is shown on the left side. There are three sectors of LAD. The first, at scattering angles from 85 to 113^o, consists of two back-to-back planes of scintillators, comprised of two sectors of the current "panel 4" of the CLAS6 TOF. The middle sector, covering angles from 110 to 145^o, contains a back-to-back pair of "panel-3" TOF sectors, followed by a single layer of panel-4 and a double layer of panel-3 for a total of five thicknesses of scintillator (although with diminishing solid angle as the distance to the target increases). The third sector covers angles from 145 to 175^o with the same five thicknesses of scintillator as the middle sector. Layout courtesy of M. Fowler.

The road to a full proposal

In order to present a full proposal, we will need to perform extensive simulations and rate calculations in order to optimize the kinematics and determine the necessary beam time. We will also continue analyzing existing data, both from Hall B and Hall A.

As part of the new DOE approved data mining proposal, we will continue analyzing the CLAS eg2 data presented above. This analysis will guide the preparation of the full proposal.

In addition, the triple coincidence experiment (E07-006) that ran in Hall A during 2011 (E07-006) acquired a large amount of semi-inclusive ^{4}He(*e,e'N*) data at Q^2 = 2 GeV^2 and and x=1.2 where the backward recoil protons were detected in BigBite and the backward neutrons in the HAND detector. An example of the on-line analysis is shown in Fig 4.

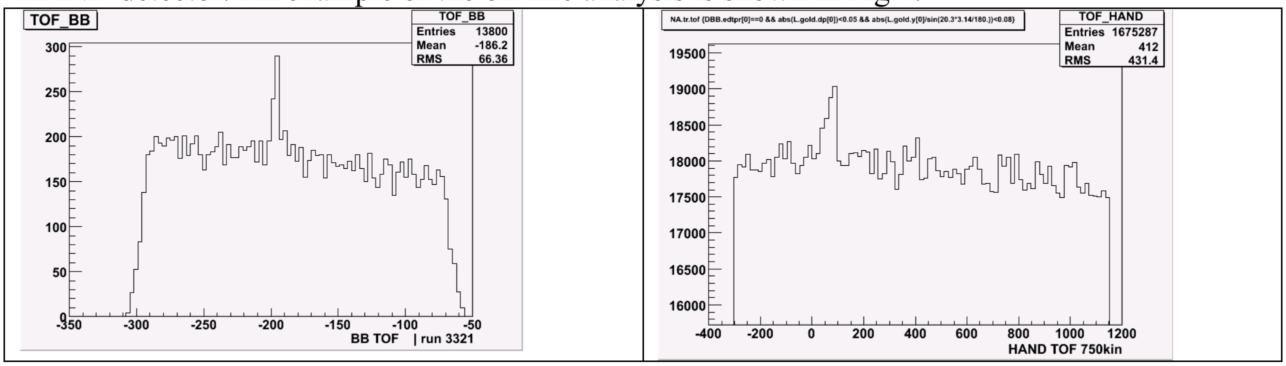

Figure 4: Online results from exp E07-006. (left) the ^{4}He(*e,e'p*) coincidence timing spectrum. The recoil protons were collected with BigBite at 92^0 in coincidence with an electron in the HRS. (right) the ^{4}He(*e,e'n*) coincidence timing spectrum measured at the same time as the (*e,e'p*) spectrum. The recoil neutrons were detected in HAND at 92^o. The peaks show the real coincidence of recoil proton and neutron with the electrons.

These data are being analyzed to try to relate the high momentum recoil nucleons with SRC. The software tools that will be developed in this analysis will be used to identify the SRC in ^{4}He based on the recoil particle information. Preliminary outcomes of this study will also be important input in preparing this proposal.

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