Nuclear Exclusive and Semi-inclusive Measurements with a New CLAS12 Low Energy Recoil Tracker: ALERT Run Group

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We propose a comprehensive physics program to investigate the quark and gluon structure of light nuclei, namely deuterium and ^{4}He, through coherent and incoherent exclusive and semi-inclusive Deep Virtual Compton Scattering (DVCS) and Deep Virtual Meson Production (DVMP). Coherent DVCS off nuclei is a particularly powerful tool for nuclear tomography through the access of partons position in the transverse plane. An additional focus of this program is the study of the effect of the nuclear medium on the structure of nucleons. We propose a next generation nuclear physics measurements in which low energy recoil nuclei are detected. The tagging of recoiling nuclei especially in semi-inclusive reactions will be realized for the first time in these measurements. This powerful technique will provide unique information about the nature of medium modification including the EMC effect through its dependence on the nucleon virtuality. Finally, we propose to measure tagged DVCS on light nuclei both for quasi-free neutron and bound nucleon GPDs. In both cases, we want to study nuclear effects and their manifestation in GPDs including the effect of Final State Interactions in the measurements of the bound nucleon beam spin asymmetries.

At the heart of this program is the Low Energy Recoil Tracker (ALERT) in addition to the CLAS12 detector. The ALERT detector is composed of a stereo drift chamber for track reconstruction and an array of scintillators for particle identification. Coupling these two types of fast detectors ensure that ALERT detector can be included in the trigger to reject background efficiently, while keeping the material budget as low as possible to detect low energy particles. ALERT will be installed inside the solenoid magnet instead of the CLAS12 Silicon Vertex Tracker. We will use a gas target straw filled with deuterium or ^{4}He at 3 atm.

The ALERT run group needs 11 GeV longitudinally polarized electron beam. Although the two main targets are ^{4}He and deuterium, we also need to run hydrogen and ^{4}He targets at different beam energies for detector calibration.

Proposal 1: Partonic Structure of ^{4}He and deuterium nuclei

We propose to study the partonic structure of ^{4}He and deuterium by measuring the Beam Spin Asymmetry (BSA) in both coherent DVCS and DVMP. In the latter, coherent production of neutral pions and phi mesons will be measured. Despite its simple structure, a light nucleus such as ^{4}He has a density and a binding energy comparable to that of heavier nuclei. Therefore, studying ^{4}He nucleus, one can learn typical features of the partonic structure of atomic nuclei. In addition, due to its spin-0, only one chiral-even GPD, $H^A(x,\xi,t)$, and one chiral-odd, $H_T^A(x,\xi,t)$, parameterize its partonic structure at twist-2 while two GPDs, $H_A^{twist-3}(x,\xi,t)$ and $\tilde{H}_A^{twist-3}(x,\xi,t)$ arise at twist-3. The latter describes partonic spin-orbit correlations in the nucleus.

A major goal of this proposal is to cover a wide kinematical range and collect higher statistics leveraging the knowledge obtained during eg6 running, where, for the first time, exclusive coherent DVCS off ^{4}He was successfully measured in the CLAS E-08-024 experiment. The real and imaginary parts of the ^{4}He Compton Form factors (CFFs) will be extracted in a model independent way from the experimental asymmetries, allowing us to access the nuclear transverse spatial distributions of partons and their spin correlations. The spin-1 nature of the deuterium, however, leads to nine GPDs, at leading twist. However, only a combination of the three GPDs (H_1, H_3 and H_5) is accessible through BSA measurements. Through these measurements, we will have a first direct sensitivity to the GPD H_3, which is related to the quadrupole form factor of the deuteron.

The other focus of this proposal is to measure exclusive coherent phi meson electroproduction off a ^{4}He target. The kinematic regime to be explored includes very low |t| up to the first diffractive minimum as found in ^{4}He elastic scattering ($|t'| \approx 0.6$ GeV^2), Q^2 up to 12 GeV^2, and x_B up to 0.4. The phi meson will be detected primarily through the charged K^+K^- channel, with the neutral $K_S^0 K_L^0$ channel also available through $K_S^0 \to \pi^+\pi^-$. Differential cross-sections for phi electroproduction off ^{4}He will be measured for the first time.

The ALERT detector provides a unique opportunity to study the gluonic structure of a dense light nucleus. The average transverse gluonic density of the ^{4}He nucleus can be extracted within a GPD framework using the measured longitudinal cross-section of coherent phi production. Additionally, threshold effects of phi production can be explored by exploiting the ALERT detector's large transverse acceptance of low |t| events. This experiment will complement the previously approved experiment E12-12-007 that will study the gluonic distribution of the proton using a very similar framework.

Proposal 2: Tagged EMC measurements of light nuclei

We propose to measure semi-inclusive deep inelastic scattering from light nuclei (deuterium and ^{4}He). The detection of the low energy recoil (p, ^{3}H and ^{3}He), in addition to the scattered electron, will provide unique information about the nature of the EMC effect and its dependence on the bound nucleon virtuality and momentum, distinguishing events where the interacting nucleus was slow, as described by a mean field scenario, or fast, very likely belonging to a correlated pair. In particular, the proposed experiment will provide stringent tests leading to clear differentiation between the many models describing the EMC effect. Indeed conventional nuclear physics explanations of the EMC effect, in terms of medium effects mainly based on Fermi motion and binding effects, yield very different predictions, compared to exotic scenarios, where bound nucleons basically loose their identity when embedded in the nuclear medium.

The experiment will also provide the data needed to test our understanding of final state interactions in ^{4}He and its impact on semi-inclusive measurements of the EMC effect. The scattered electrons will be detected in CLAS12, while the fragments of the nuclear target will be detected in ALERT.

Proposal 3: Tagged DVCS

Deeply Virtual Compton Scattering on the proton is set to reveal a 3 dimensional picture of how quarks and gluons are distributed inside of the nucleon. For light nuclei, the Fermi motion of the bound nucleon complicates the picture. However, the case of relatively large Fermi momenta provides an interesting opportunity to study medium modifications because it corresponds to configuration where two nucleons are separated by a small distance. In this region, the short-range part of the N-N potential originates from short-range exchanges whose nature is not well understood.

We propose investigating these configurations with DVCS using ^{4}He and deuterium targets, where the final state includes a recoiling nucleus (less one nucleon) and the nucleon, which participated in the hard process. The DVCS beam spin asymmetry on a (quasi-free) neutron will be measured through tagging a recoil proton from a deuteron target. Similarly, another measurement on the neutron will be performed by detecting a recoiling triton from a ^{4}He target. Taking the ratio of these asymmetries at fixed DVCS kinematics for different Fermi momenta will provide very important information on the modification of the nucleon as function of the N-N separation.

We will also measure the impact of final state interactions on incoherent DVCS measurements to help understand the measurements performed on helium during the previous CLAS E-08-024 experiment. The measurement of neutron DVCS by tagging the recoil proton from a deuterium target is complementary to the previously approved CLAS12 experiment E12-11-003 which will also measure quasi-free neutron DVCS by detecting the scattered neutron.