Study of Short-Range nuclear Correlations in light nuclei using the BeAGLE event generator

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Abstract

Nuclear dynamics at short distances among nucleons is one of the most outstanding phenomena in nuclear physics. Understanding the role of QCD in generating nuclear forces is important for uncovering the underlying physics of Short-Range Correlations (SRCs). In recent years, SRCs has been observed from light to heavy nuclei using fixed target experiments at Jefferson lab via high energy electron-nucleus scattering. In this talk, I will talk about the opportunity of studying SRCs using light nuclei with collider experiments, e.g., the Electron-Ion Collider (EIC). The experimental technique of studying the light nuclei can be based on exclusive processes with tagging final-state particles, in order to fully control the initial state of the target wavefunction. In particular, incoherent diffractive production of J/ψ particle off deuteron will be presented. In addition, the spectral function in light nuclei has been recently modeled in the BeAGLE event generator, where the decay kinematics of the light nuclei and their influence on the very forward detector design at the EIC will be discussed.

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1 Introduction

Deep inelastic scattering measurements conducted at accelerator facilities around the world [1,2] uncovered that the bound nucleons in nuclei are significantly modified in terms of their parton distribution functions (PDFs) in the valence quark region (x within $0.3 < x < 0.7$). This is known as the “EMC effect". The microscopic origins of the EMC effect are still not fully understood nearly four decades after its original discovery [3,4]. More recently, quasielastic proton and lepton scattering measurements uncovered another remarkable phenomenon, that of short range nucleon-nucleon correlations (SRCs) [5,6]. SRCs are pairs of strongly interacting nucleons at close proximity. They dominate the high-momentum distribution of the many-body nuclear wave function and exhibit universal behavior in nuclei from Deuterium to the heaviest nucleus [7–10].

Experimental data from JLab suggest a strong link between SRCs and the EMC effect [5,11–14]. Specifically, they suggest that the underlying mechanism of nucleon modifications could be caused by short-range correlated nucleon pairs with high internal nucleon momentum, for instance, a quasi-deuteron inside the nucleus. However there are alternative phenomenological models that can explain the EMC effect without involving SRCs; see Ref. [5] for a recent review. However, for the mystery of nuclear modification, there is much more than just the EMC effect and its correlation to the SRCs. For example, the gluon modification at low-x for heavy nucleus could be attributed by gluon shadowing effect [15] or gluon saturation effects [16], observed by ultra-peripheral collisions (UPC) at the Large Hadron Collider (LHC) experiments [17].

The goal of this present study is to explore possibility of gluon modification and its connection to the SRC phenomena. Whether the parton modification mechanism shares some features of universality in different nucleus? Is it sensitive to the average nuclear density, e.g., $\sim A^{1/3}$, or is it sensitive to the local density that is characterized by the SRC pairs? Generally, the parton modifications are shown in terms of a suppression (or an enhancement) on the inclusive cross section; however, what would the modification manifest in the parton distributions, e.g., gluon b_{T} distribution? Hereby we explore this physics using the simplest nuclear system - deuteron, at the upcoming Electron-Ion Collider (EIC) with capability of detecting forward-going nucleons with high precision. The nuclear wavefunction of the deuteron, or the initial momentum/spatial configuration, can be accessed experimentally by tagging a spectator nucleon event-by-event. We use the momentum information based on the spectator nucleon as an experimental handle on the nuclear configuration, and we propose to measure the momentum transfer $-t$ distribution of the incoherent J/ψ production. The cross section would provide important insights to the mechanism of parton modification and its impact on the gluon spatial distributions. See Fig. 1 for an illustration of the physics process. This work is based on publication Ref. [18].

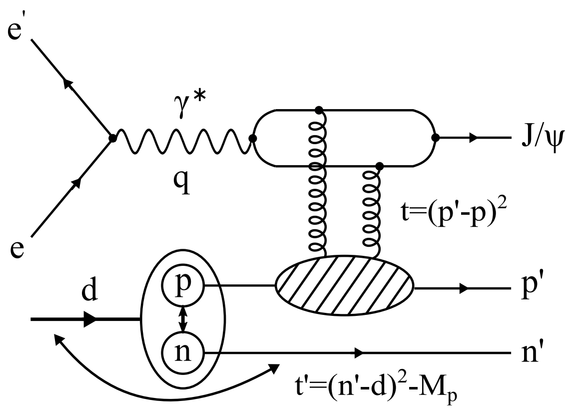

Figure 1: Diagram of incoherent diffractive J/ψ productions in electron-deuteron scattering

2 BeAGLE event generator and Far-Forward detectors

BeAGLE Monte Carlo event generator is a hybrid model of PYTHIA 6.4 [19], DPMJET 3 [20], and FLUKA [21,22]. For details, see Refs. [18]. For modeling the nuclear effects, BeAGLE utilizes the nuclear PDF (nPDF), nuclear shadowing effects, intra-nuclear cascade, etc. However, for modeling the deuteron, a different approach was used, where the light-front wave function of deuteron is implemented and the nucleon momentum distribution is based on the Ciofi-Simula parametrization in Ref. [23]. In this study, we not only simulate the BeAGLE events but also pass the events to the simulations of Far-Forward (FF) detectors, which include a B0 tracker, Off-Momentum Detector (OMD), Roman Pots (RP), and Zero-Degree Calorimeter (ZDC). The details of these simulations, detector parameters, and beam-related effects, can be found in Ref. [18] and the recently published Yellow Report [24].

3 Result

In Fig. 2, we show the three-momentum of spectator nucleon distributions, P_m, in leading proton (left) and leading neutron (right), respectively, in ed scattering with an incoherent J/ψ particle produced at the EIC energy. For each panel, there are three different results are shown, namely the MC Truth, simulation results with only the acceptance effect, and full simulations of the FF detectors and beam-related effects. For the neutron spectator, the acceptance effect is close to 100% from low p_m to relative high p_m, while it is subject to large smearing effect at low p_m due to the ZDC resolution. However, for the proton spectator, the qualitative observation is quite the opposite to that of neutron spectator, where the acceptance effect is worse at high p_m value but with very small smearing effect seen at low p_m. This indicates that the proton tagging would have a much better resolution than of neutron. The proton tagging is in some way more important, because in order to access the free neutron, proton tagging is required. For the neutron tagging, it is important to perform a symmetric analysis on the leading proton where free proton data will be available at the EIC or has been measured by HERA. In this physics process, there are other observables can be measured, e.g., the momentum transfer $-t$ distributions, which is a Fourier transformation of the gluon source distribution. We propose that if there is a universal mechanism between the parton distribution and the SRC effect, we will see a difference in the shape of the gluon distribution when compared the SRC region to the non-SRC region. For details, see Ref. [18].

The SRC region is known as the range of $p_m > 300$ MeV/c. Therefore, the SRC physics in this measurement will be less sensitive to the momentum/energy resolution of the spectator tagging, but more on the acceptance. However, in other measurements, e.g., free neutron structure functions, low p_m resolution will be more important. Given the performance of the FF detectors and study of the beam-related effects, the proposed measurement of incoherent J/ψ off deuteron with spectator tagging is feasible at the EIC. The projected integrated luminosity for this measurement is 30 fb^{-1}.

4 Conclusion

In this work we have presented the feasibility study of spectator tagging at the Electron-Ion Collider (EIC) in the Far-Forward region based on physics simulation of BeAGLE. The process of interest is the incoherent J/ψ particle production off deuteron in electron-deuteron scattering, where the spectator momentum information can provide an experimental control on the initial nuclear configuration. The simulation results have shown that both proton and neutron tagging are possible with very good acceptance, where proton tagging has a better momentum resolution. The proposed measurements are sensitive to the mechanism of gluon modification and its spatial distributions. These studies will provide an important experimental baseline for diffractive and exclusive physics program at the EIC.

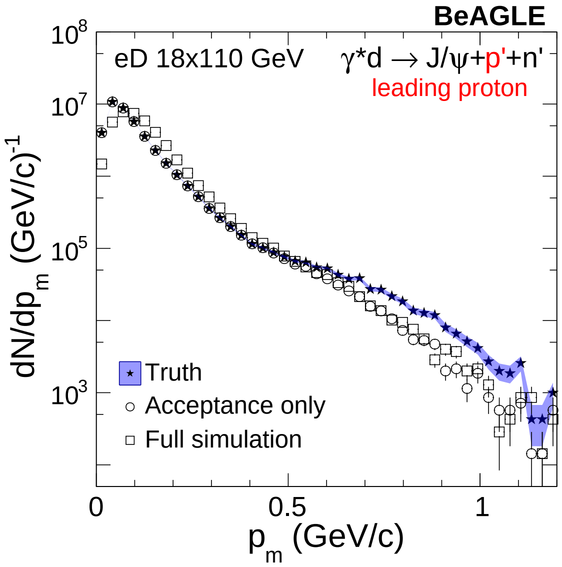

Figure 2: Distribution of the three-momentum of the spectator nucleon in events associated with incoherent diffractive J/ψ vector meson production in ed collisions are shown for the BeAGLE event generator. The left panel is for the neutron spectator case, where the right panel is for the proton spectators. The simulations at the generator level, with acceptances effects only, and for the full simulations, are shown with solid, open circles, and open squared markers, respectively.

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