Summary of Session on Color and Nuclei at the EIC

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One of the long standing goals of nuclear physics is to effectively demonstrate that Quantum Chromo Dynamics (QCD), with its colored quark-gluon degrees of freedom, is the ultimate source of the strong nuclear force. Exclusive and semi-exclusive processes in nuclei are essential in studies of the role of color in nuclei. This is because manifestation of the underlying quark-gluon degrees of freedom of QCD naturally gives rise to a distinct set of phenomena in exclusive processes on nucleons and nuclei. One such fundamental prediction of QCD is the phenomenon of Color Transparency (CT), that refers to the vanishing of the final (and initial) state interactions of hadrons with the nuclear medium in exclusive processes at high momentum transfer [1]. The availability of high-energy beams provides the opportunity to search for the presence of QCD in nuclei. The proposed electron ion collider (EIC) will be the next generation QCD machine. The study of high energy color transparency at the EIC promises to be an effective probe of the dynamics of the strong interaction. In addition it can also probe the small size components of hadrons and are intrinsically related to the access to Generalized Parton Distributions (GPDs).

For exclusive process, the color coherence property of QCD, i.e. the suppression of the interaction of small sized color singlet configuration, is an attractive probe of the high energy dynamics of the strong interaction. This arises from the well proven QCD factorization theorems for hard exclusive processes [2, 3] and the fact that the interaction cross section for the color dipole is proportional to the square of the transverse size of the dipole [4]. At the EIC one would access an intermediate range of dipole transverse sizes that would probe a region between the hard and soft QCD regimes, as shown in Fig. 1.

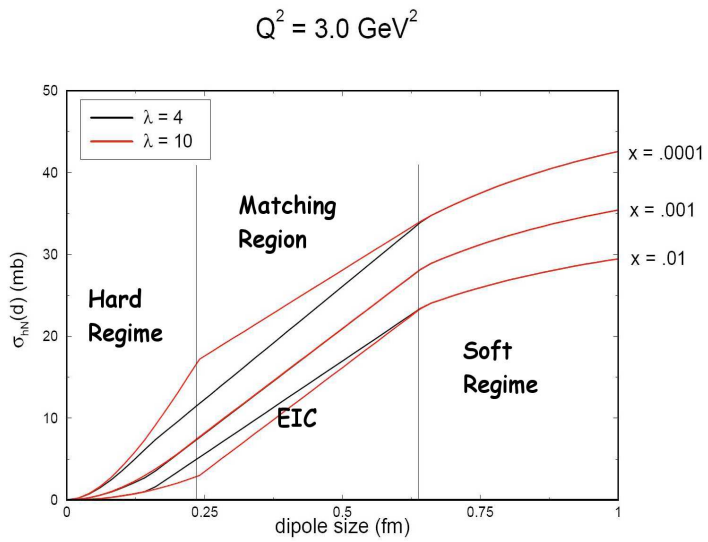

Figure 1: The color dipole cross section vs the transverse size of the dipole for different x at $Q^2 = 3$ GeV^2. The region accessible at the EIC is marked.

The QCD phenomena of CT can be described as a combination of two effects 1) selection of the small size state (squeezing) and 2) propagation of this small size state in the medium while it stays small (freezing). The "squeezing" phenomena is readily achieved at high energies, and CT at high energies is well established. In fact the weakness of interaction of small size configurations with nucleons is routinely used to describe deep-inelastic scattering (DIS) measurements at the *ep* collider, HERA. The "freezing" phenomena, however, is the main challenge for CT, even if the interaction of the elementary process is dominated by small size configurations, they are not frozen. They evolve with time and expand after the interaction to an average configurations [5]. In the range of momentum transfers to the target nucleon that are feasible at the EIC ($-t < 2$ GeV^2), the expansion is fast and therefore the CT effects for the target fragmentation region is small, however in the current fragmentation region "freezing" is a significant effect and therefore one can probe CT effects in the propagation of the hadronic components of the photon.

The above paragraphs are a summary of issues that were discussed in the overview talk *[M. Strikman]*. The slides from all the talks can be found at *http://www.phy.anl.gov/mep/EIC-NUC2010/program.html* . The rest of the summary discusses the possible physics measurements that were presented at the workshop along with a brief discussion of the on going work at the 6 GeV JLab and the proposed measurements at 12 GeV JLab.

1 Possible Physics Measurements

The following possible measurements were discussed in the overview presentation *[M. Strikman]*.

1.1 Vector Meson Production

At the EIC the coherent and incoherent diffractive production of vector mesons in $\gamma^* + A \to MA$ and coherent diffractive $\gamma + A \to MA$, can be used to map out the color fluctuations in photons which arise from the interplay between soft and hard contributions. However, one must be able to distinguish between the four types of diffractive processes, i) the coherent which dominate at small $-t$, ii) coherent excitation of nuclear levels which results in emission of an additional final state photons with energy in the 100 MeV range, iii) incoherent diffraction which require the detection of final state neutrons and iv) inelastic incoherent diffraction which dominate at large $-t$ and are challenging to detect.

A significant nucleon number (A) dependence of the "squeezing" effect is predicted for coherent vector meson production from light nuclei. Therefore, it maybe advantageous to focus on the coherent vector meson production from light nuclei such as ^2H,^3He,^4He. The other advantages of light nuclei include, the lack of excited bounds states, the coherence lengths at the EIC kinematics would be larger than the nuclear radius and the possibility of studying two nucleon coherent interactions and rescattering effects.

1.2 Branching Exclusive Process

Other interesting processes that can be studied at the EIC include $\gamma + A \rightarrow \rho + (N\pi) + A - 1$, where the pion is produced close to threshold. These reactions can provide insight into the "squeezing" of the recoil nucleon and should also be performed on light nuclei where the expansion times are moderate. The EIC will also allow the study of processes involving large c.m. angle scattering on quark clusters in the target or projectile. These include $\gamma^* + A \rightarrow \pi^+\pi^0 A^*$ in the current fragmentation region and $\gamma^* + A \rightarrow \rho^0\pi^+ A^*$ in the target fragmentation region. By comparing the the transparency measured in these processes to the transparency measured in exclusive processes one can quantify the pattern of formation time, in other words the "freezing" effects of the small size configuration. These processes can also help test the role of chiral degrees of freedom in hard interactions.

2 Ongoing Work at 6 and 12 GeV JLab

Over the last decade several experiments at JLab have used the 6 GeV beam to search for the onset of CT. These measurements have not observed any indication of CT in proton knock-out reactions. However, the onset of CT in exclusive pion production has been observed recently and there are several calculations which are able to explain these measurements. These include calculations using relativistic Glauber type calculations along with the quantum diffusion model of CT *[W. Cosyn]* and the Giessen transport model based on a Boltzmann-Uehling-Uhlenbeck framework (GiBUU) *[K. Gallmeister]*. The GiBUU model with its microscopic description of DIS seems to have resolved a long standing problem of large disagreement between theory and experiment on the transverse strength of pion electro production cross sections. They also predict that the CT observed in pion electroproduction is primarily due to the suppression of this transverse cross section. Some of these will be tested by experiments proposed for the 12 GeV JLab. However, the exclusive pion and proton production experiments will be very challenging at the EIC due to extremely forward angle kinematics of the recoil particles. In a collider geometry it is important to measure the recoils in order to ensure exclusivity.

The results from a recent experiment to measure the onset of CT in rho meson production from nuclei was also presented *[L. El Fassi]*. These results are consistent with the expected early onset of CT in mesons and the observations for pions. Rho meson production will also be continued at 12 GeV JLab and the simulations for the EIC kinematics look very promising as well. These simulations strongly support the feasibility of a program on vector meson production on light nuclei at the EIC, which was motivated at the beginning of this paper.

Finally, the strong linkages that exist between GPDs and CT were discussed and importance of measuring GPDs of light nuclei *[S. Liutti]* was elaborated. An EIC would aid in a systematic study of the interdependence of the transverse momentum of the quark, k_T, the impact parameter b and the momentum fraction of quark x.

In Summary, the EIC will provide a wide range of opportunities to study the interplay of small and large transverse distance effects, and map out the space-time evolution of small wave packets over distances of the order of nuclear radii. This exploration of the role of color in nuclei will complement the ongoing programs at 6 GeV JLab and the upcoming 12 GeV

program at JLab.

References

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