Diffractive Physics at eRHIC

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eRHIC facility opens up a variety of new regions in hadron physics. Its kinematics immediately implies that it allows us to survey the small-x high parton density of nuclei by using the DIS off large nuclei, which is now being extensively discussed by many people. Here, however, we discuss other physics possibilities in eRHIC. The small-x kinematics also means that eRHIC is a very useful device for the diffractive physics. In the following, we mainly consider both of the diffractive processes in the eA and polarized ep scatterings. As for physics under nuclear environment in eA collisions, there are, at least, two important directions. The first is to see purely matter effects on production/propagation of hadrons, which are never observed in fundamental processes. The second is to consider a large nucleus as an amplifier of tiny effects which could exist even in fundamental processes. Based on these, we propose the following subjects as interesting physics in eRHIC.

1. **Diffractive vector meson productions**
   In the small-x kinematics, amplitude of the vector meson (V) production on a nucleon (N): $\gamma^{(*)}+N \to V+N$ can be given simply as $\mathcal{A} \propto \psi_\gamma \otimes \sigma_{q\bar{q}N} \otimes \psi_V$, where ψ_γ and ψ_V are LC wavefunctions of photon and vector mesons. The dipole cross section $\sigma_{q\bar{q}N}$ is a scattering amplitude between a $q\bar{q}$ pair and a nucleon. When one has a hard scale (such as heavy quark mass or large Q^2) in the process, one can evaluate $\sigma_{q\bar{q}N}$ by perturbative QCD [1]. A standard perturbative calculation is based on the small dipole approximation for a $q\bar{q}$ pair and the dipole cross section is given as $\sigma_{q\bar{q}N} \propto b^2 \alpha_s xG(x, Q^2)$ where b is a transverse separation between q and $\bar{q}$, and $xG(x, Q^2)$ is the gluon distribution in a proton. While the dipole approximation works well for J/ψ, it is not a good approximation for ψ' simply due to its large size $r_{\psi'} \approx 0.8$fm. We have shown that the value of ψ' to J/ψ production ratio is significantly improved by taking the multi-pole effects into account [2]. Also, the multi-pole contributions drastically affect the dipole cross section for $b > 0.4$fm [3]. For moderately large transverse size $b < 1$fm, $\sigma_{q\bar{q}N}$ becomes much smaller than the above result and is still below the hadronic bound $\sigma \sim 20$mb for $x = 10^{-3}$. Therefore, in a sense, our calculation enlarged the region of applicability of perturbative QCD. We have also calculated the diffractive $\Upsilon(1S, 2S, 3S)$ productions [2]. Since the precise data for Υ are not available at the moment (only 2 points at HERA), it would be better to measure it in eRHIC.

   Because the deviation from the dipole approximation for ψ' case is directly related to its large size, we naively expect that this effect will be further amplified in nuclei (due to multiple scattering or large overlapping). However, it depends on the kinematics: whether the vector meson is formed within a nucleus or outside of it. In the diffractive process with small-x kinematics, the 'formation length' of a $q\bar{q}$ pair is much larger than the nuclear radius. Hence, the vector meson is expected to be formed outside of the nucleus. If so, the matter effects should be addressed as the modification of the dipole cross section $\sigma_{q\bar{q}N}$. Usually this effect is expected to be small (color transparency), but for moderate Q^2 and if we measure the excited(2S) vector mesons in the final state, the transverse size of a $q\bar{q}$ pair is not so small and we expect some matter effects. On the other hand, if the vector meson is formed inside of a nucleus, we can further enjoy the other matter effect: the scattering of a vector meson off nucleons in a nucleus. These two different situations will be realized by changing the energy of a nucleus, which should be possible in eRHIC. Lastly, though many people already claimed, we also should emphasize that the diffractive J/ψ production off nuclei is one of the best ways to extract the nuclear gluon distribution. Only eRHIC can do this experiment.

2. **J/ψ and ψ' productions by eA collisions**

   Related to, but slightly different from the above subject, let us consider the inclusive production cross section of J/ψ and ψ' by eA collision, $e + A \to J/\psi(\psi') + X$. Formation and absorption of charmonium in hadron collisions attract considerable interests and are currently under a controversial situation whether the color octet process is really the dominant contribution. While the J/ψ production in pp collision allows the color octet process and is believed to be dominated by it, the main contribution in the electroproduction of charmonium $e+p \to J/\psi+X$ at low z is the color singlet process. This was confirmed by the comparison of HERA experiment with theoretical calculations. Hence, use of the electron beam is advantageous to study matter effects on the propagation of charmonium in nuclei, since the propagation of the color singlet object seems to be under control. We can extract the information on the nuclear absorption of J/ψ and ψ' in more reliable way. On the other hand, we do not know the absorption of the color octet objects in nuclei and have much ambiguities.

   Using the standard technique [4] and the J/ψ-N, ψ'-N absorption cross section calculated by the model based on perturbative QCD [3], we find $\sigma(e+A \to J/\psi)/A\sigma(e+p \to J/\psi) = 0.75$ and $\sigma(e + A \to \psi')/A\sigma(e + p \to \psi') = 0.54$ for Au target. Here, J/ψ coming from decays of χ-states are not included in this estimate, but can be incorporated.

   In addition to the conventional nuclear absorption, a new mechanism of ψ' suppression is proposed due to the mass reduction of $D\bar{D}$ mesons [5]. QCD sum rule calculation tells us that the mass of D-meson at normal nuclear mater density is reduced by about 100MeV. It indicates ψ' can decay into $D\bar{D}$ inside the nucleus, because $D\bar{D}$ threshold comes below the mass of ψ'. A crude estimate shows that, with momentum of a produced ψ' being about 10GeV, the suppression factor

$\sigma(e+A \to \psi')/A\sigma(e+p \to \psi')$ decreases to ≈ 0.2. Observation of such effects may be possible at the eRHIC facility.

3. **Spin-dependent diffractive processes**
   Study of the spin-dependent diffractive process is of special interest for various hadron properties. It has been argued that the diffractive production of J/ψ in the longitudinally polarized ep collision, $\vec{\gamma}+\vec{p} \to J/\psi+\vec{p}$, is not a good probe of the polarized gluon distribution $\Delta g(x, Q^2)$ of the proton [6]. In the forward case, $t=0$, the asymmetry A_{LL} is shown to vanish in the non-relativistic limit within the collinear approximation.[1] However, inclusion of explicit intrinsic momenta of quarks and gluons is expected to provide a finite asymmetry even at $t=0$ [7, 8]. If so, this process is one of the ideal tools for the measurement of $\Delta g(x, Q^2)$ free from the notorious color octet contribution.

   In addition to the possibility of measuring the gluon polarization, the spin-dependent diffractive processes allow us to obtain many new quantities of hadrons. By observing the helicities of the final state, we can extract the helicity flip skewed parton distribution. This distribution is sensitive only to the gluons in the nucleon. On the other hand, if one can measure a complete set of helicity amplitudes, it may be possible to discuss the D-wave component of the vector meson wave function. Further experimental test of s-channel helicity conservation at high energy is also possible.

4. **Difference between gluonic Pomeron and pionic Pomeron**
   Usually the Pomeron is believed to be a very complicated gluonic state. When the perturbative calculation is somewhat justified, the QCD Pomeron can be described as two (Reggeized) gluons and obeys the BFKL equation. This is the 'hard' Pomeron. On the other hand, it is sometimes argued that there is an another Pomeron (the 'soft' Pomeron) with different properties, and of non-perturbative origin [9]. At present, we have no definite idea how to describe the soft Pomeron. However, an interesting suggestion was made by Bjorken [10] that the soft Pomeron or high energy scattering could be described as scattering between pion clouds of each hadrons.[2] This picture implies that the soft Pomeron is most likely a multi-pionic state. How can we distinguish the gluonic and pionic Pomerons? A possible way could be the diffractive scattering off nuclei, which completely belongs to the eRHIC physics. The pion cloud is a small distortion of the vacuum and thus should be intimately related to chiral condensate. Therefore if the vacuum property changes, the pion cloud will also get modified. Recently, it has been discussed that partial restoration of the chiral symmetry (reduction of the chiral condensate) is already

[1] At non-zero momentum transfer to the proton, $t \neq 0$, we expect finite asymmetry even in the non-relativistic limit, which could reveal the spin-dependent structure of the Pomeron.

[2] See also Ref. [11] which partly incorporated pionic contributions in the ladders between two gluons.

seen in nuclear medium [12]. Therefore, if the pionic Pomeron propagates in nuclear medium, which is expected to occur in eA diffractive scattering, its properties will change. Also, if the gluonic Pomeron is related to the gluon condensate, we can again expect change due to medium modification of the gluon condensate. However, these two changes will be different and we could distinguish the gluonic and pionic Pomerons. Indeed, the gluon condensate is much less affected compared to the chiral condensate in nuclear medium [13].

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