The Color Glass Condensate and particle production in the forward rapidity region

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Hadron production in the forward rapidity region is considered in the Color Glass Condensate approach to high energy deuteron-nucleus collisions. The projectile deuteron is treated via collinear factorization and pQCD formalism while the nucleus is described as a Color Glass Condensate. It is shown that both DGLAP evolution of the projectile wave function and JIMWLK evolution of the target are essential for a proper understanding the RHIC data in the forward rapidity region.

1. High energy proton (deuteron)-nucleus collisions

In the forward rapidity region of a high energy hadron-hadron (nucleus) collision, one probes the large x partons of the projectile hadron and the small x degrees of freedom in the nucleus. While the standard Color Glass Condensate approch (for a review see [1], [2]) can describe both the projectile and target when the relevant x is small, i.e. in mid rapidity and at high energy, it is not expected to work when the projectile x is large, $O(1)$. Therefore, it is essential to devise a formalism which can treat the large x degrees of freedom in the projectile properly. This has been done in [3] where the projectile was treated as a collection of quarks and gluons which then scatter on the nucleus described by the Color Glass Condensate formalism. Furthermore, Q^2 evolution of the projectile wave function was taken into account and the radiation vertex was treated exactly, i.e. without the usual small x approximation.

The cross section for hadron production in high energy proton (deuteron)-nucleus collisions is given by

$$\frac{d\sigma^{pA\rightarrow hX}}{dY\, d^2P_t\, d^2b} = \frac{1}{(2\pi)^2}\int_{x_F}^{1} dx\, \frac{x}{x_F}\Big\{ f_{q/p}(x,Q^2)\; N_F[\frac{x}{x_F}P_t, b]\; D_{h/q}(\frac{x_F}{x},Q^2) + f_{g/p}(x,Q^2)\; N_A[\frac{x}{x_F}P_t, b]\; D_{g/h}(\frac{x_F}{x},Q^2)\Big\} \quad (1)$$

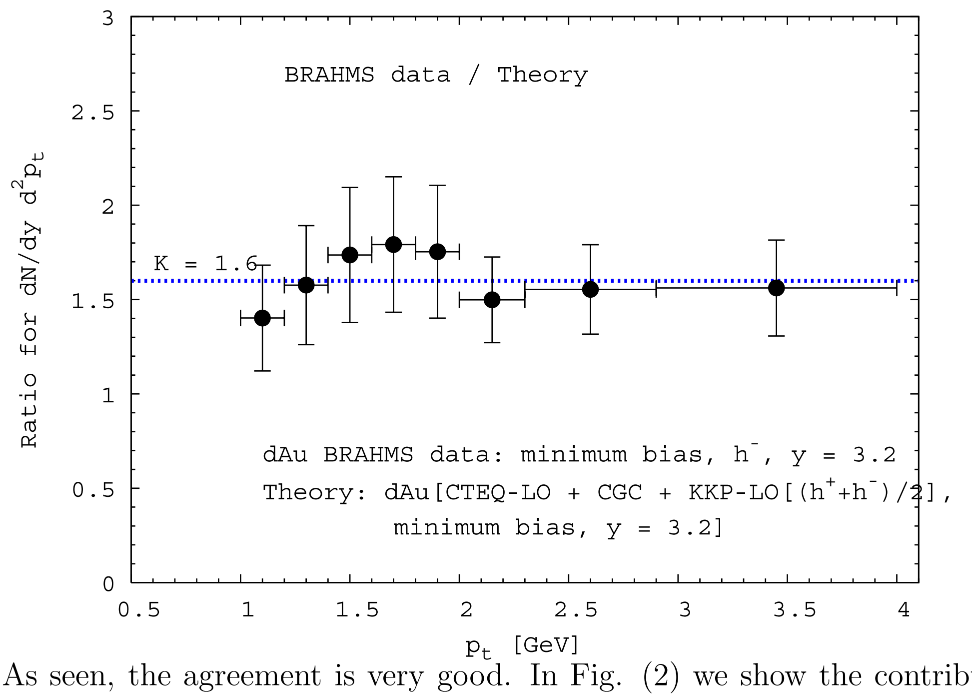
where Y and P_t are the rapidity and transverse momentum of the produced hadron while x_F denotes its Feynman-x. The parton distribution function of a proton or deuteron is denoted $f_{q/p}(x,Q^2)$ while $D_{h/q}(z,Q^2)$ is the parton-hadron fragmentation function. Both satisfy the DGLAP evolution equation which resums large logs of Q^2. The target information is contained in the dipole cross sections N_F, N_A which satisfy the JIMWLK evolution equation which resums large logs of $1/x$ and includes multiple scattering from the target.

They are given by

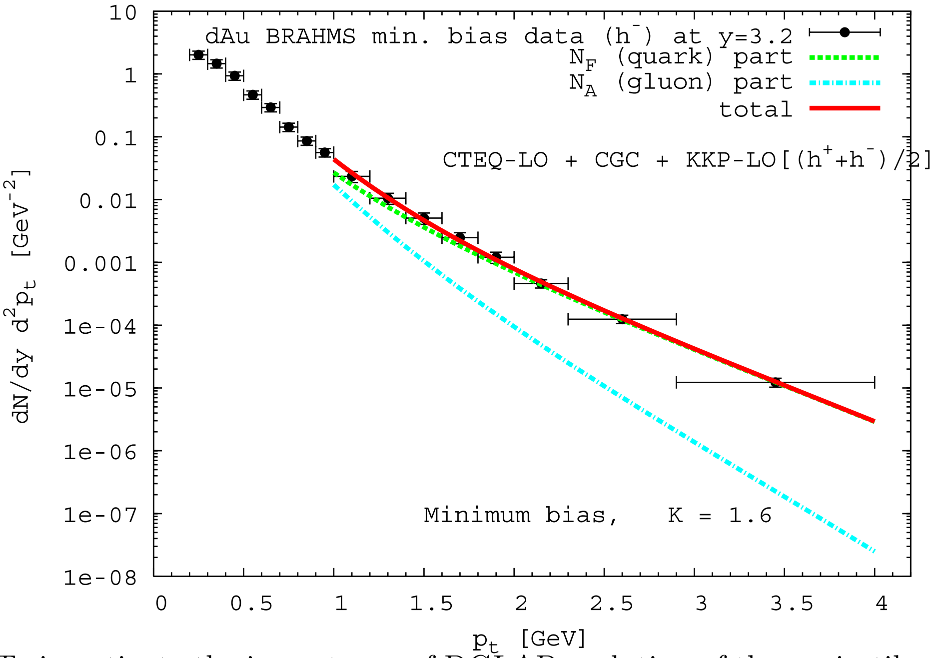
$$N_F(r_t, b) \equiv \frac{1}{N_c} \mathrm{Tr_c} \langle V^\dagger(b - r_t/2) V(b + r_t/2) - 1 \rangle$$
$$N_A(r_t, b) \equiv \frac{1}{N_c^2 - 1} \mathrm{Tr_c} \langle U^\dagger(b - r_t/2) U(b + r_t/2) - 1 \rangle \quad (2)$$

where V (U) is a matrix in the fundamental (adjoint) representation of the $SU(N_c)$ group and includes multiple scattering of the quark (gluon) on the target nucleus.

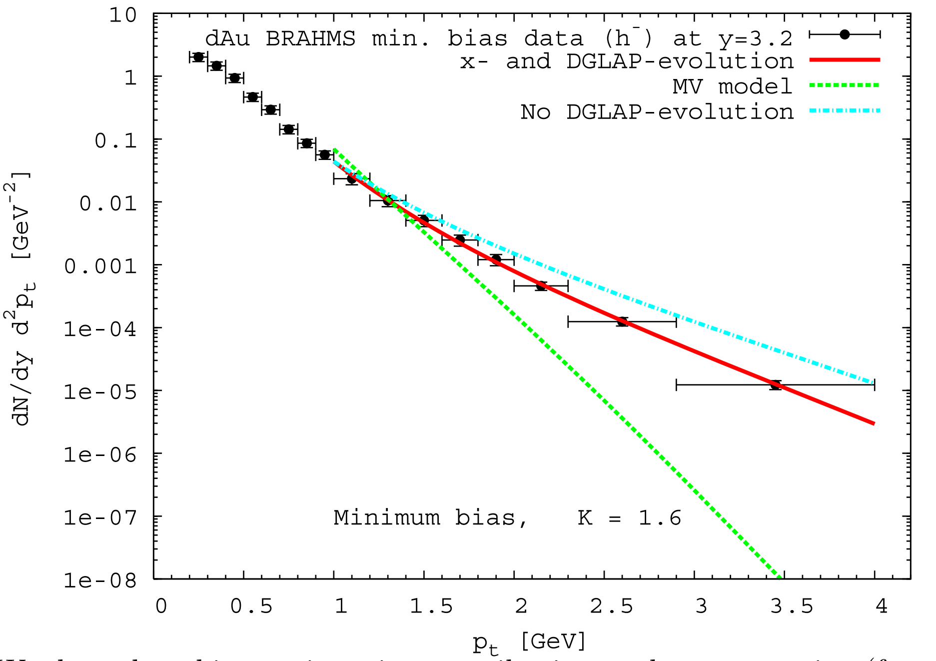
We use the standard parameterizations of the parton distribution and fragmentation functions, for example, CTEQ. To get the dipole cross sections N_F, N_A, one needs to solve the JIMWLK equation (or its large N_c limit, known as the BK equation). There has been some work done in this direction, however, it is much more convenient to use one of the available parameterizations of the dipole cross section which have been tested before. Here, we use the parameterization due to Kharzeev et al. (denoted KKT) for our numerical results (see [3] for the details). We show the transverse momentum spectra of the produced hadron at $y = 3.2$ in deuteron-gold collisions at RHIC in Fig. (1) where we have divided our results by the BRAHMS data [4] for ease of comparison and used a (p_t independent) K factor of 1.6.



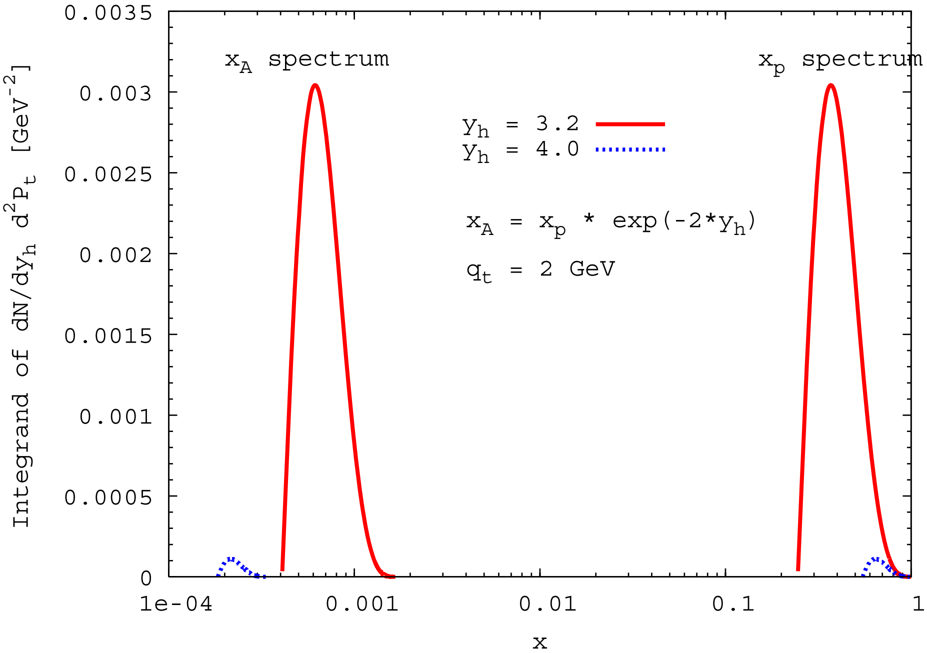
As seen, the agreement is very good. In Fig. (2) we show the contribution of quarks and gluons in the deuteron wave function to the cross section separately. Clearly, quarks are the dominant parton species in the deuteron at forward rapidity and their inclusion is essential.



To investigate the importance of DGLAP evolution of the projectile wave function and the JIMWLK evolution of the target, we show the cross section without DGLAP evoltuion of the projectile and without the small x evolution of the target (denoted MV model) in Fig. (3). It is clear that one needs to include both effects for a satisfactory description of the data.



We show the x kinematic region contributing to the cross section (for $q_t = 2GeV$) in Fig. (4) for $y = 3.2$, appropriate for BRAHMS and $y = 4$ where STAR detector can measure hadrons. As expected, one proves very large values of x in the projectile ($x_p \sim 0.1 - 0.7$) and very small values of x in the target ($x_A \sim 10^{-3} - 10^{-4}$).



In summary, we have shown that in the forward rapidity region, it is essential to include both DGLAP evolution of the projectile deuteron wave function and the small x evolution of the target nucleus. We have reproduced the BRAHMS data on single hadron production at RHIC at $y = 3.2$ and made predictions for single hadron production at $y = 4$ which seem to be confirmed by preliminary data from STAR [5].

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