Rapidity Asymmetry in High-energy $d + A$ Collisions

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In contrast to the recent prediction of high $p_T$ hadron suppression within the parton saturation model, it is shown that multiple parton scattering suffered by the projectile will enhance high $p_T$ hadron spectra in $d + A$ collisions relative to a superposition of binary $p + p$ collisions at RHIC. A stronger enhancement in the forward rapidity region of the projectile is also predicted, resulting in a unique rapidity asymmetry of the hadron spectra at high $p_T$. The shape of the rapidity asymmetry should be reversed for low $p_T$ hadrons that are dominated by soft and coherent interactions which suppress hadron spectra in the projectile rapidity region. The phenomenon at the LHC energies is shown to be qualitatively different because of parton shadowing.

I. INTRODUCTION

Recent experiments [1,2] at the Relativistic Heavy-ion Collider (RHIC) have shown a significant suppression of high $p_T$ hadron spectra in central $Au + Au$ collisions that was predicted [3,4] as a consequence of parton energy loss or jet quenching in dense matter. In addition, the same mechanism is predicted to produce azimuthal anisotropy in high $p_T$ hadron spectra [5] that was also observed in experiments at RHIC [6]. This is a dramatic departure from the heavy-ion collisions at the SPS energies where no significant suppression of high $p_T$ spectra is observed [7,8]. Since theoretical studies [9–13] of parton propagation in a dense medium all show that the parton energy loss induced by multiple scattering is proportional to the gluon density, RHIC data thus indicate an initial gluon density in central $Au + Au$ collisions at the RHIC energies that is much higher than that in a large cold nucleus [14].

More precise extraction of the parton energy loss from the final hadron suppression in $A + A$ collisions, however, requires the understanding of normal nuclear effects in $p + A$ collisions. As pointed out by many early [15–17] and recent [18–20] studies, the high $p_T$ hadron spectra can also be modified by initial multiple scatterings in $p + A$ and $A + A$ collisions giving rise to the observed Cronin effect. Within a multiple
scattering model, the high $p_T$ hadron spectra are normally enhanced relative to $p + p$ collisions, except in the kinematic region where the EMC effect [21] is important (The EMC effect is the depletion of parton distributions in $x \sim 0.2 - 0.8$ in nuclei caused by the nuclear binding effect). Such a normal nuclear enhancement will not affect the interpretation of the hadron suppression in central $A + A$ collisions as a consequence of jet quenching, though inclusion of it is important for more precise extraction of parton energy loss and the initial gluon density.

A very different mechanism was recently proposed for the observed high $p_T$ hadron suppression based on the parton saturation model [22] which also predicts a similar suppression in $p + A$ collisions at RHIC, in contrast to the predicted enhancement by the multiple parton scattering model. While such a model is not yet checked against the existing $p + A$ collisions for energies up to $\sqrt{s} = 40$ GeV where enhancement of hadron spectra for $p_T > 2$ GeV/$c$ has been successfully explained by the multiple scattering model, the up-coming data of $d + A$ collisions at RHIC will attest the relevance of parton saturation at the RHIC energies.

In this letter, we will point out an additional feature in the rapidity dependence of the Cronin enhancement due to multiple parton scattering in $d + A$ collisions. Such a rapidity dependence was also studied recently by Vitev [23]. However, we predict here a unique rapidity asymmetry of high $p_T$ hadron spectra due to stronger Cronin enhancement in the forward (projectile) region as a result of the transverse momentum broadening of the initial partons inside the projectile. The shape of the rapidity asymmetry will also depend on the nuclear modification of the parton distributions inside a nucleus, in particular at small $x$. As one decreases $p_T$, the parton shadowing will reduce the hadron spectra in the forward region, thus changing the rapidity asymmetry. When soft and coherent interactions become dominant at very low $p_T < 1$ GeV/$c$, the shape of the rapidity asymmetry will be reversed because of the strong suppression of hadron production in the projectile region relative to a superposition of binary $p + p$ collisions. We will calculate the rapidity asymmetry within a perturbative QCD (pQCD) parton model and study the effect of nuclear modification of parton distributions.
FIG. 1. Pseudo-rapidity distribution of charged hadrons in minimum-biased $d + Au$ collisions at $\sqrt{s} = 200$ GeV from the HIJING [25] model.

In a Glauber multiple parton scattering model, large $p_T$ spectra are generally enhanced relative to the binary model of hard scattering. It can be shown [24] that a combination of absorptive corrections and the power-law behavior of perturbative parton cross section leads to a nuclear enhancement at high $p_T$ that decreases as $1/p_T^2$. The same absorptive processes suppress the spectra relative to the binary model at low $p_T$, where soft processes dominate and the $p_T$ spectra deviate from a power-law behavior. Since the pQCD model cannot be applied to soft processes, one has to resort to phenomenological models like the string model in which coherent particle production is modeled by a string excitation for each participant nucleon. Shown in Fig. 1 is the rapidity distribution (integrated over transverse momentum) of charged hadrons in minimum-biased $d + Au$ collisions at $\sqrt{s} = 200$ GeV from the HIJING Monte Carlo model [25], which employs the string model for soft and coherent interactions. Because most of the soft particles are produced through string fragmentation, their number should then be proportional to the number of participants. The rapidity distributions of hadrons from the string should also follow their parent nucleons. Since there are more target nucleon participants than projectile nucleons in $d + A$ collisions, the hadron rapidity distribution is thus asymmetrical with respect to $\eta = 0$. For high $p_T$ hadrons, the underlying processes are hard parton scatterings. The multiplicity should be approximately proportional to the number of binary scatterings and the rapidity distributions should be approximately symmetric with respect to $\eta = 0$. This is roughly the case for high $p_T$ hadrons in HIJING model as shown in Fig. 1. One, however, can notice some asymmetric effect in the rapidity distribution of large $p_T$ hadrons. This is partially due to the coherence between transverse jets and the beam remnants, which is responsible for the asymmetric pedestal effect underlying a jet event in $p + A$ collisions. In addition, energy and quark number conservation will
also cause some asymmetric effects. These effects are most important in the large rapidity region. It is expected that they are small in the central rapidity region.

Though the HIJING model has incorporated hard processes, it has not included transverse momentum broadening of initial partons. For this purpose, we use the pQCD model as employed in Ref. [17]. We will use a lowest order (LO) pQCD-inspired parton model in which the inclusive particle production cross section in $pp$ collisions is given by [26]

$$\frac{d\sigma_{pp}^h}{dyd^2p_T} = K \sum_{abcd} \int dx_a dx_b d^2k_{aT} d^2k_{bT} g_p(k_{aT}; Q^2) g_p(k_{bT}; Q^2) f_{a/p}(x_a, Q^2) f_{b/p}(x_b, Q^2) \frac{D_{h/c}^0(z_c; Q^2)}{\pi z_c} \frac{d\sigma}{dt}(ab \to cd),$$  

where $D_{h/c}^0(z_c; Q^2)$ is the fragmentation function of parton $c$ into hadron $h$ as parameterized in Ref. [27] from $e^+e^-$ data, and $z_c$ is the momentum fraction of a parton jet carried by a produced hadron. The $K \approx 1.5$ (at $\sqrt{s} = 200$ GeV) factor is used to account for higher order QCD corrections to the jet production cross section. The parton distributions $f_{a/N}(x, Q^2)$ in a nucleon are given by the MRS D′ parameterization [28]. The initial transverse momentum distribution $g_N(k_T, Q^2)$ is assumed to have a Gaussian form,

$$g_N(k_T, Q^2) = \frac{1}{\pi \langle k_T^2 \rangle_N} e^{-k_T^2/\langle k_T^2 \rangle_N}.$$  

Following [29], we choose a $Q$-dependent average initial transverse momentum,

$$\langle k_T^2 \rangle_N(Q^2) = 1.2(\text{GeV}^2) + 0.2\alpha_s(Q^2)Q^2,$$

which should include both the intrinsic and pQCD radiation-generated transverse momentum in this LO calculation. The form of the $Q$-dependence and the parameters are chosen to reproduce the experimental data [17], especially at low energies. Following the same approach as in Refs. [29,30], we choose $Q^2$ to be $Q^2 = 2st\hat{u}/(s^2 + t^2 + \hat{u}^2)$.

To take account of multiple initial-state scattering, we assume that the inclusive differential cross section for large $p_T$ particle production is still given by a single hard parton-parton scattering. However, due to multiple parton scattering prior to the hard processes, we consider the initial transverse momentum $k_T$ of the beam partons to be broadened. Assuming that each scattering provide a $k_T$ kick which also has a Gaussian distribution, we can effectively change the width of the initial $k_T$ distribution. Then the single inclusive particle cross section in minimum-biased $p+A$ collisions is,

$$\frac{d\sigma_{pA}^h}{dyd^2p_T} = K \sum_{abcd} \int d^2b t_A(b) \int dx_a dx_b d^2k_{aT} d^2k_{bT} g_A(k_{aT}, Q^2, b) g_p(k_{bT}, Q^2) f_{a/p}(x_a, Q^2) f_{b/A}(x_b, Q^2, b) \frac{D_{h/c}^0(z_c; Q^2)}{\pi z_c} \frac{d\sigma}{dt}(ab \to cd),$$

where $t_A(b)$ is the nuclear thickness function normalized to $\int d^2b t_A(b) = A$. We will use the Woods-Saxon form of nuclear distribution for $t_A(b)$ throughout this paper.
unless specified otherwise. The parton distribution per nucleon inside the nucleus (with atomic mass number $A$ and charge number $Z$) at an impact parameter $b$,

$$f_{a/A}(x, Q^2, b) = S_{a/A}(x, b) \left[ \frac{Z}{A} f_{a/p}(x, Q^2) + (1 - \frac{Z}{A}) f_{a/n}(x, Q^2) \right],$$

is assumed to be factorizable into the parton distribution in a nucleon $f_{a/N}(x, Q^2)$ and the nuclear modification factor $S_{a/A}(x, b)$, for which we take both the new HI-JING [31] and EKS [32] parameterizations. The initial parton transverse momentum distribution inside a projectile nucleon going through the target nucleus at an impact parameter $b$ is still a Gaussian with a broadened width

$$\langle k_T^2 \rangle_A(Q^2) = \langle k_T^2 \rangle_N(Q^2) + \delta^2(Q^2)(\nu_A(b) - 1).$$

The broadening is assumed to be proportional to the number of scattering $\nu_A(b)$ the projectile suffers inside the nucleus, which is assumed to be given by

$$\nu_A(b) = \sigma_{NN} t_A(b) = \sigma_{NN} \frac{3A}{2\pi R_A^2} \sqrt{1 - b^2/R_A^2},$$

in a hard sphere nuclear distribution, where $R_A = 1.12A^{1/3}$ fm and $\sigma_{NN}$ is the inelastic nucleon-nucleon cross section. We also assume that $k_T$ broadening during each nucleon-nucleon collision $\delta^2$ also depends on the hard momentum scale $Q = P_{T}^{jet}$ in the parameterized form,

$$\delta^2(Q^2) = 0.225 \frac{\ln^2(Q/\text{GeV})}{1 + \ln(Q/\text{GeV})} \text{ GeV}^2/c^2,$$

which is chosen to best fit the existing experimental data in $p + A$ collisions [17] up to $\sqrt{s} = 40$ GeV. The predictive power of this model lies in the energy and flavor dependence of the hadron spectra. It is straightforward to also calculate hadron spectra in $d + A$ collisions, incorporating the initial $k_T$ broadening and parton shadowing. We have tried different forms of nuclear distribution for deuteron and find little difference in the final results. So we will still use the Woods-Saxon distribution for $t_d(b)$. In heavy nuclear $A + A$ collisions, one can incorporate parton energy loss induced by the dense medium through modified fragmentation functions [33].

The pQCD model described above has been compared to experimental data for $pp$, $p\bar{p}$ and $pA$ collisions at various energies [17]. One found that both the intrinsic $k_T$ and the nuclear broadening are very important to describe the existing data in $pp$ and $pA$ collisions, especially at around SPS energies. One can find some more detailed description of this pQCD-inspired model in Ref. [17]. We will restrict ourselves to the study of the rapidity dependence of the nuclear modification in $d + A$ collisions at RHIC and LHC energies in this paper.
FIG. 2. Calculated rapidity distributions of charged hadrons with large transverse momentum in minimum-biased $d+Au$ collisions at $\sqrt{s}=200$ GeV. The dashed lines correspond to a superposition of binary $N+N$ collisions. The dotted lines have nuclear broadening of initial parton transverse momentum but without parton shadowing. The solid and dot-dashed lines use the EKS [32] and HIJING [31] parameterization of parton shadowing, respectively. The spectra have been scaled by the numbers in parentheses.

Neglecting initial transverse momentum, the initial momentum fractions are related to the transverse momentum and rapidities of the final jets by $x_1 = x_T(e^{y_1} + e^{y_2})/2$, $x_2 = xT(e^{-y_1} + e^{-y_2})/2$, $x_T = 2E_T/\sqrt{s}$, where $E_T$, $y_1$ and $y_2$ are the transverse momentum and rapidities of the produced jets, respectively. Large positive rapidities, therefore, correspond to large parton fractional momentum $x_1$ from the projectile and small momentum fraction $x_2$ from the target. Conversely, negative rapidities correspond to small $x_1$ and large $x_2$. In our parton model calculation, we assume the final hadron rapidity to be the same as that of the fragmenting jets. Shown in Fig. 2 are the rapidity distributions of the charged hadron spectra for four different values of $p_T$. Without nuclear modification of the parton distributions (shown as dotted lines), the $k_T$ broadening of the projectile partons enhances the particle spectra. The enhancement is the strongest in the forward (projectile) region, thus giving rise to a rapidity asymmetry. The EKS [32] parameterization has a strong anti-shadowing at $x_2 \sim 0.1–0.2$ for partons from the nuclear target. Such strong anti-shadowing further enhances the rapidity asymmetry (shown as solid lines). However, the HIJING [31]
parameterization has mostly shadowing in this region and thus reduces the rapidity asymmetry in the spectra (dot-dashed line) which is still visible for \( p_T > 3 \text{ GeV}/c \). At \( p_T > 10 \text{ GeV}/c \), the target parton distribution at \( x_2 \sim 0.2 - 0.8 \) is suppressed due to the nuclear binding, which is known as the EMC effect [21]. This reduces the hadron spectra in the backward (target) rapidity region and thus further enhances the rapidity asymmetry.

As one decreases the transverse momentum so that parton shadowing in the target becomes significant, the hadron spectra in the forward region are strongly suppressed. It can even overcome the enhancement caused by transverse momentum broadening. In this case the rapidity asymmetry is reversed, as shown in Fig. 2 for \( p_T = 1.5 \text{ GeV}/c \). This is much like the asymmetric rapidity distribution of soft particles produced via soft and coherent interactions as shown in Fig. 1. The validity of the parton model at \( p_T = 1.5 \text{ GeV}/c \) may be questionable. However, it clearly shows the trend of the rapidity asymmetry as one changes the value of \( p_T \).

![FIG. 3. Calculated rapidity distributions of charged hadrons with large transverse momentum in minimum-biased \( d + Pb \) collisions at \( \sqrt{s} = 5.5 \text{ TeV} \).](image)

We also show in Fig. 3 similar rapidity distributions for \( d + Pb \) collisions at \( \sqrt{s} = 5.5 \text{ TeV} \) where one has access to much larger values of transverse momentum. At such high energies and transverse momenta, the parton scattering cross is much flatter in \( p_T \) than at lower energies. Therefore, the final hadron spectra are less sensitive to the transverse momentum broadening due to initial multiple scatterings. The rapidity asymmetry caused by the \( k_T \) broadening is thus very weak, as shown by the dotted lines. The nuclear modification of the parton distributions in the target is causing
most of the rapidity asymmetry in the spectra at these energies. Here we used only EKS [32] parameterization of nuclear modification of the parton distributions. The HIJING [31] parameterization does not have any scale dependence, which is very important at LHC energies since the shadowing still has significant effects on jet production with large transverse momentum.

To demonstrate the $p_T$ dependence of the effect of parton shadowing and $k_T$ broadening, we show in Fig. 4 and 5 the nuclear modification factors defined as the ratio of charged hadron spectra in $d + A$ over that in $p + p$ normalized to the averaged number of binary nucleon collisions,

$$R_{dA}(p_T, y) \equiv \frac{d\sigma^h_{AB}/dyd^2p_T}{2Ad\sigma^h_{pp}/dyd^2p_T}. \quad (9)$$

At the RHIC energy, the transverse momentum broadening enhances the hadron spectra for $p_T = 2 - 8$ GeV/$c$ in both forward and backward rapidity regions. The exact enhancement in this $p_T$ region depends on the parton shadowing and anti-shadowing. The enhancement in the forward rapidity is larger than in the backward region as demonstrated by the rapidity asymmetry in Fig. 2. For $p_T > 8$ GeV/$c$, the EMC effect of the nuclear modification of parton distribution starts to suppress the hadron spectra. Such a suppression is stronger in the target rapidity region than in the projectile region. We also find that the suppression due to the EMC effect is stronger for kaons than pions. For $p_T < 2$ GeV/$c$, parton shadowing suppresses the hadron spectra in the case of HIJING parameterization. However, the pQCD model might not be valid anymore in this small $p_T$ region for a quantitative calculation. The nuclear modification factor for $d + Pb$ collisions at the LHC energy shown in Fig. 5 has much smaller variation and the Cronin enhancement is also smaller.
FIG. 4. The nuclear modification factor $R_{dA}(p_T, y)$ for $d + Au$ collisions at $\sqrt{s} = 200$ GeV. $k_T$ broadening and different parameterization of parton shadowing are included.

In summary, we have studied the rapidity distribution of hadron spectra in high-energy $d + A$ collisions, in particular the rapidity asymmetry caused by multiple parton scatterings. The effects of initial multiple parton scatterings are incorporated via an impact-parameter dependent nuclear shadowing of parton distributions and the broadening of the initial $k_T$ carried by partons before they collide and produce high $p_T$ hadrons. At low $p_T$ parton shadowing suppresses the hadron spectra in the projectile rapidity region, giving rise to a rapidity asymmetry much like the soft particle production via soft and coherent interactions in a string model. However, as one increases $p_T$, hadron production is dominated by hard parton scatterings and the rapidity distribution is becoming more symmetric. Within a pQCD model, transverse momentum broadening via initial multiple scattering enhances the hadron spectra in the projectile region at moderate $p_T = 3 - 8$ GeV/c, causing a rapidity asymmetry opposite to that of soft hadrons. This is in sharp contrast to the prediction of the parton saturation model [22]. The coming data of $d + Au$ collisions from RHIC can easily distinguish those two models and will be important to verify whether jet quenching due to parton energy loss is truly the underlying mechanism for the observed hadron suppression in central $A + A$ collisions.
FIG. 5. The nuclear modification factor $R_{dA}(p_T,y)$ for $d + Pb$ collisions at $\sqrt{s} = 5.5$ TeV.

We should also caution that our pQCD model cannot take into account the non-perturbative effects that can cause some rapidity asymmetry at very large rapidities. Such non-perturbative effect is responsible for the asymmetric pedestal effect underlying a jet event in $p + A$ collisions. Our conclusions are more robust within the central rapidity region where such non-perturbative effect and constraints by total energy conservation are not yet important.

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[1] K. Adcox et al. [PHENIX Collaboration], Phys. Rev. Lett. 88, 022301 (2002) [arXiv:nucl-ex/0109003].
[2] C. Adler et al., [STAR Collaboration], Phys. Rev. Lett. 89, 202301 (2002) [arXiv:nucl-ex/0206011].

[3] M. Gyulassy and M. Plumer, Phys. Lett. B 243, 432 (1990).

[4] X. N. Wang and M. Gyulassy, Phys. Rev. Lett. 68, 1480 (1992).

[5] X. N. Wang, Phys. Rev. C 63, 054902 (2001) [arXiv:nucl-th/0009019]; M. Gyulassy, I. Vitev and X. N. Wang, Phys. Rev. Lett. 86, 2537 (2001) [arXiv:nucl-th/0012092].

[6] C. Adler et al. [STAR Collaboration], Phys. Rev. Lett. 90, 032301 (2003) [arXiv:nucl-ex/0206006].

[7] M. M. Aggarwal et al. [WA98 Collaboration], Phys. Rev. Lett. 81, 4087 (1998) [Erratum-ibid. 84, 578 (1998)] [arXiv:nucl-ex/9806004].

[8] X.-N. Wang, Phys. Rev. Lett. 81, 2655 (1998) [arXiv:hep-ph/9804384].

[9] M. Gyulassy and X. N. Wang, Nucl. Phys. B420, 583 (1994) [arXiv:nucl-th/9306003]; X. N. Wang, M. Gyulassy and M. Plumer, Phys. Rev. D 51, 3436 (1995) [arXiv:hep-ph/9408344].

[10] R. Baier et al., Nucl. Phys. B484, 265 (1997) [arXiv:hep-ph/9608322]; Phys. Rev. C 58, 1706 (1998) [arXiv:hep-ph/9803473].

[11] B. G. Zhakharov, JETP letters 63, 952 (1996) [arXiv:hep-ph/9607440].

[12] M. Gyulassy, P. Lévai and I. Vitev, Nucl. Phys. B594, 371 (2001) [arXiv:nucl-th/0006010]; Phys. Rev. Lett. 85, 5535 (2000) [arXiv:nucl-th/0005032].

[13] U. Wiedemann, Nucl. Phys. B588, 303 (2000) [arXiv:hep-ph/0005129].

[14] E. Wang and X. N. Wang, Phys. Rev. Lett. 89, 162301 (2002) [arXiv:hep-ph/0202105].

[15] M. Lev and B. Petersson, Z. Phys. C 21, 155 (1983).

[16] T. Ochiai, S. Date and H. Sumiyoshi, Prog. Theor. Phys. 75, 288 (1986).
[17] X. N. Wang, Phys. Rev. C 61, 064910 (2000) [arXiv:nucl-th/9812021].

[18] Y. Zhang, G. Fai, G. Papp, G. G. Barnafoldi and P. Levai, Phys. Rev. C 65, 034903 (2002) [arXiv:hep-ph/0109233].

[19] B. Z. Kopeliovich, J. Nemchik, A. Schafer and A. V. Tarasov, Phys. Rev. Lett. 88, 232303 (2002) [arXiv:hep-ph/0201010].

[20] I. Vitev and M. Gyulassy, Phys. Rev. Lett. 89, 252301 (2002) [arXiv:hep-ph/0209161].

[21] J. Ashman et al. [European Muon Collaboration], Phys. Lett. B 202, 603 (1988).

[22] D. Kharzeev, E. Levin and L. McLerran, arXiv:hep-ph/0210332.

[23] I. Vitev, arXiv:nucl-th/0302002.

[24] X. N. Wang, Phys. Rept. 280, 287 (1997) [arXiv:hep-ph/9605214]; E. Wang and X. N. Wang, Phys. Rev. C 64, 034901 (2001) [arXiv:nucl-th/0104031].

[25] X. N. Wang and M. Gyulassy, Phys. Rev. D 44, 3501 (1991); M. Gyulassy and X. N. Wang, Comput. Phys. Commun. 83, 307 (1994) [arXiv:nucl-th/9502021].

[26] J. F. Owens, Rev. Mod. Phys. 59 (1987) 465.

[27] J. Binnewies, B. A. Kniehl and G. Kramer, Z. Phys. C 65, 471 (1995) [arXiv:hep-ph/9407347]; J. Binnewies, B. A. Kniehl and G. Kramer, Phys. Rev. D 53, 3573 (1996) [arXiv:hep-ph/9506437].

[28] A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C 4, 463 (1998) [arXiv:hep-ph/9803445].

[29] J. F. Owens and J. D. Kimel, Phys. Rev. D 18, 3313 (1978).

[30] R. P. Feynman, R. D. Field and G. C. Fox, Phys. Rev. D 18, 3320 (1978).

[31] S. Y. Li and X. N. Wang, Phys. Lett. B 527, 85 (2002) [arXiv:nucl-th/0110075].
[32] K. J. Eskola, V. J. Kolhinen and C. A. Salgado, Eur. Phys. J. C 9, 61 (1999) [arXiv:hep-ph/9807297].

[33] X. N. Wang, Z. Huang and I. Sarcevic, Phys. Rev. Lett. 77, 231 (1996) [arXiv:hep-ph/9605213]; X. N. Wang and Z. Huang, Phys. Rev. C 55, 3047 (1997) [arXiv:hep-ph/9701227].