Nuclear Modification Factors for Hadrons At Forward and Backward Rapidities in Deuteron-Gold Collisions at $\sqrt{s_{NN}}$ = 200 GeV

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Abstract. We report on charged hadron production in deuteron-gold reactions at $\sqrt{s_{NN}} = 200$ GeV. Our measurements in the deuteron-direction cover $1.4 < \eta < 2.2$, referred to as forward rapidity, and in the gold-direction $-2.0 < \eta < -1.4$, referred to as backward rapidity, and a transverse momentum range $p_T = 0.5-4.0$ GeV/c. We compare the relative yields for different deuteron-gold collision centrality classes. We observe a suppression relative to binary collision scaling at forward rapidity, sensitive to low momentum fraction (x) partons in the gold nucleus, and an enhancement at backward rapidity, sensitive to high momentum fraction partons in the gold nucleus.

Keywords: Hadron, Rapidity, Nuclear Modification
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INTRODUCTION

In 2003 the Relativistic Heavy Ion Collider (RHIC) collided deuteron and gold nuclei at $\sqrt{s_{NN}} = 200$ GeV. At this energy, most hadrons with $p_T > 2.0$ GeV/c arise from parton-parton interactions and can be used as a probe of nuclear partonic structure. Hadrons with $p_T > 2.0$ GeV/c at forward rapidity $1.4 < \eta < 2.2$ are sensitive to low x partons in the gold nucleus $0.001 < x < 0.03$. Hadrons at backward rapidity $-2.0 < \eta < -1.4$ are sensitive to high x partons in the gold nucleus $0.04 < x < 0.5$. It has been predicted that gluon saturation at small x will suppress hadronic yields at forward rapidity [1] with the transverse momentum scale for the onset of the gluon saturation set by $Q_s^2[\mathrm{GeV}^2] = 0.13\ N_{coll} e^{\lambda y}$ [2] for $d + Au$ collisions at RHIC. Here $\lambda \sim 0.3$ is determined from HERA data [3] and N_{coll} is the number of nucleon-nucleon inelastic collisions. Thus, for central collisions and within our forward rapidity coverage Q_s^2 is expected to be of order $2-4$ GeV^2 and may have observable consequences. Other hadron production mechanisms, such as quark recombination [4], can also result in an effective suppression in the forward rapidity region.

Results on charged hadron yields at forward rapidity from the BRAHMS experiment have shown a suppression of the yield of hadrons in central, compared to peripheral, $d + Au$ collisions [7]. At mid-rapidity, PHENIX has reported a modest enhancement of the yield of hadrons with $p_T > 1.5$ GeV/c [8]. This enhancement, generally referred to as the “Cronin effect” is often ascribed to initial state scattering of the parton traversing the nucleus prior to the high Q^2 scattering [5]. At backward rapidities (large x), anti-shadowing and other effects of the surrounding nuclear medium (e.g. the EMC effect) [9] may compete, making predictions challenging.

RESULTS

We measured hardon via two independed methods [6]. First method directly identify hadron based on matching between hadron momentum and where it stops in the detector. The second method measures muons from light hadron decays.

We divide deuteron-gold collisions into four centrality classes based on the number of particle hits in the backward BBC counter covering $-3.9 < \eta < -3.0$. Using a Glauber model [8] and simulation of the BBC, we determine the average number of binary collisions in each centrality class. The classes are categorized as follows: $60-88\%$ ($\langle N_{coll} \rangle = 3.1 \pm 0.3$), $40-60\%$ ($\langle N_{coll} \rangle = 7.0 \pm 0.6$), $20-40\%$ ($\langle N_{coll} \rangle = 10.6 \pm 0.7$),and $0-20\%$ ($\langle N_{coll} \rangle = 15.4 \pm 1.0$).

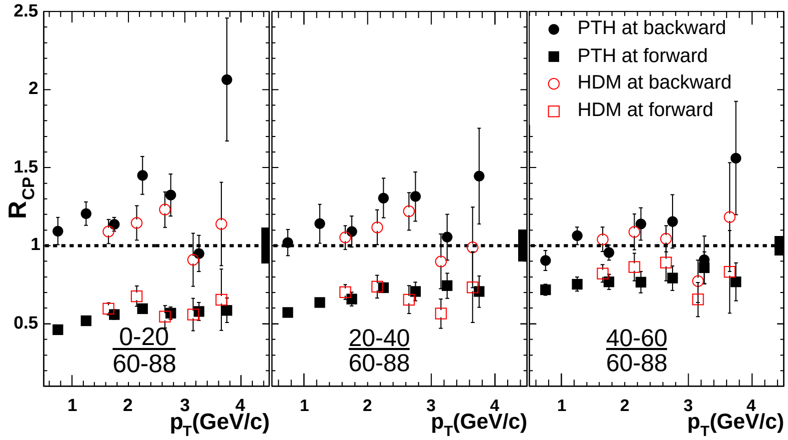

FIGURE 1. (color online). R_{cp} as a function of p_T at forward rapidity (squares) and backward rapidity (circles) for different centrality classes.

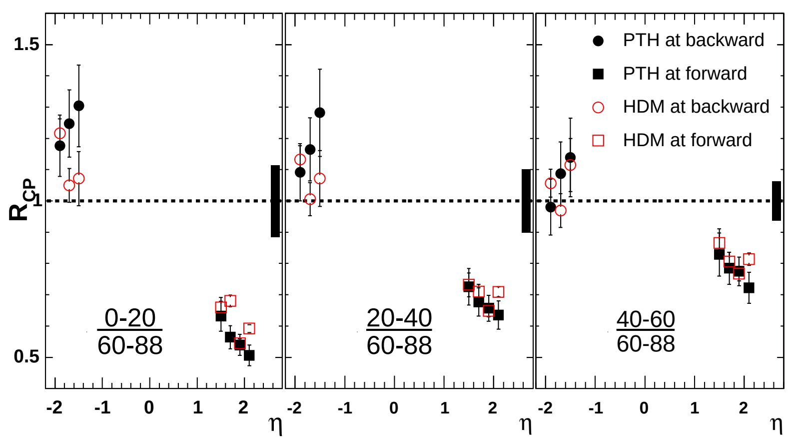

FIGURE 2. (color online). R_{cp} as a function of η for $1.5 < p_T < 4.0\,\text{GeV}/c$ for different centrality classes.

The *nuclear modification factor* R_{cp} is defined as the ratio of the particle yield in central collisions to the particle yield in peripheral collisions, each normalized by the average number of nucleon-nucleon binary collisions ($\langle N_{coll} \rangle$):

$$R_{cp} = \frac{\langle \left(\frac{dN}{d\eta dp_T} \right)^{Central} \rangle / \langle N_{coll}^{Central} \rangle}{\langle \left(\frac{dN}{d\eta dp_T} \right)^{Peripheral} \rangle / \langle N_{coll}^{Peripheral} \rangle} \tag{1}$$

The hadron R_{cp}, using the most peripheral centrality class ($60-88\%$) for normalization, is shown in Figure 1 as a function of p_T at forward and backward rapidities. The results from the punch-through hadron (PTH) and hadron decay muon (HDM) techniques are both shown and are in quite good agreement. We also show the results integrated over $1.5 < p_T < 4.0\,\text{GeV}/c$ as a function of pseudorapidity in Figure 2.

We observe that R_{cp} shows a suppression at forward rapidity that is largest for the most central events. The opposite trend is observed at backward rapidity where R_{cp} shows an enhancement that is also largest for the most central events. We observe a weak p_T dependence with slightly smaller R_{cp} values at lower p_T. We observe a clear pseudorapidity dependence at forward rapidity with R_{cp} dropping further at larger η values. Within our current uncertainties we are unable to discern any pseudorapidity dependence at backward rapidity.

In Figure 3 we compare results from the BRAHMS experiment [7] with our results at forward rapidity. The PHENIX data and the BRAHMS data are in agreement within systematic uncertainties.

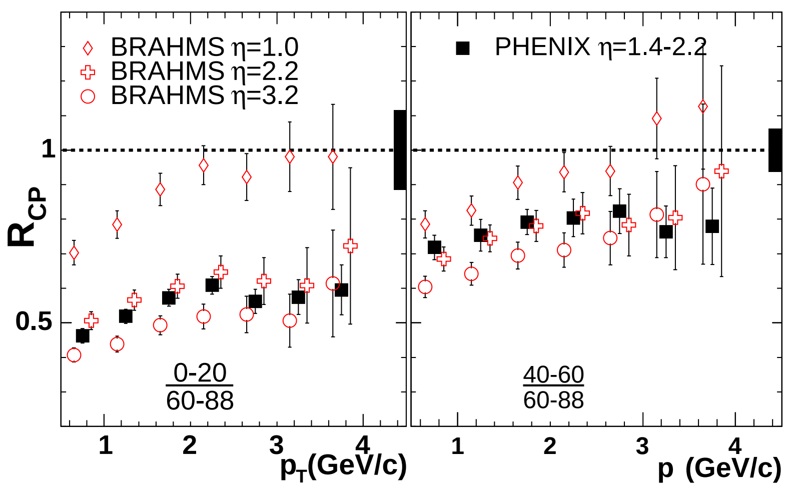

FIGURE 3. (color online). PHENIX R_{cp} as a function of p_T at forward rapidities shown as the average of the two methods. Note that the BRAHMS results are for negative hadrons at $\eta = 2.2, 3.2$ and their centrality ranges ($0-20\%/60-80\%$ and $30-50\%/60-80\%$) are somewhat different from ours.

The suppression of hadron yields relative to binary collision scaling at forward rapidity is expected from initial state nuclear effects. However, detailed comparisons with various theoretical approaches is necessary in order to discriminate between different models. In particular the lack of a strong p_T depedence at both forward and backward rapidities must be understood as the physics processes transition from “soft” to “hard” physics scales.

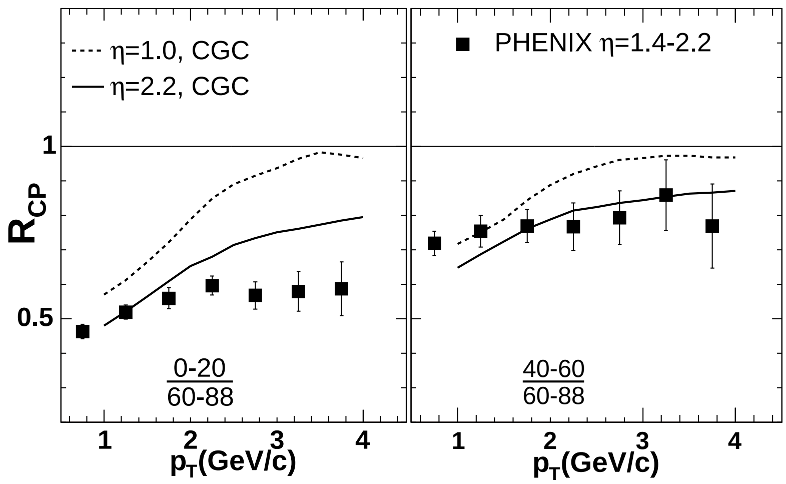

FIGURE 4. (color online). PHENIX R_{cp} as a function of p_T at forward rapidities ploted with CGC ca. Note that the CGC calculations have two free parameters fitted by BRAHMS results and their centrality ranges ($0-20\%/60-80\%$ and $30-50\%/60-80\%$) are somewhat different from ours.

SUMMARY AND DISCUSSIONS

To summarize, we observe a suppression in hadron yields relative to binary collision scaling at forward rapidities and an enhancement at backward rapidity for central relative to peripheral $d+Au$ reactions at $\sqrt{s_{NN}} = 200\,\text{GeV}$. The forward rapidity suppression is in qualitative agreement with the expectation of shadowing and saturation effects in the small x region in the gold nucleus. In figure5, we give the comparison between our measured nuclear modification from forward rapidities and the CGC calculations [2]. However, other physics effects must also be considered in understanding the full p_T and η dependence. The source of the backward rapidity enhancement, and the possible contribution of anti-shadowing of large x partons, has yet to be understood.

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