Hadron production in the forward and backward rapidities in dAu collisions at RHIC

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Abstract. We have developed new techniques to detect hadrons with the PHENIX muon spectrometers. This allows us to study the centrality dependent nuclear modification factor R_{CP} with high p_T hadrons in both forward (d direction) and backward (Au direction) pseudo-rapidities, $1 < |\eta| < 2$, in d-Au collisions at $\sqrt{s_{NN}} = 200GeV$. Preliminary results show a suppression (enhancement) of high p_T hadron production in central $0-20\%$ dAu collisions relative to the peripheral one $(60-88\%$ in centrality) at forward (backward) rapidity.

1. Introduction

The PHENIX experiment has collected $2.74nb^{-1}$ of dAu collisions from the RHIC 2003 run period. This provides the first opportunity to study the cold nuclear medium effects on particle production in dAu collisions at $\sqrt{s_{NN}} = 200GeV$. The observed suppression of high p_T particles in central AuAu collisions and enhancement in dAu collisions at central rapidity at RHIC showed the nuclear medium plays an important role in particle production.[1] In this paper, we extend our measurement of R_{CP}, defined in eq. (1), in dAu collisions from central pseudo-rapidity $\eta \sim 0$ to the forward and backward regions, $1 < |\eta| < 2$.

$$R_{CP}(p_T,\eta) = \frac{\frac{1}{<N_{coll}>}\frac{d^2N}{dp_T d\eta}(p_T,\eta)^{(central)}}{\frac{1}{<N_{coll}>}\frac{d^2N}{dp_T d\eta}(p_T,\eta)^{(peripheral)}} \tag{1}$$

where $< N_{coll} >$ is the average number of binary collisions of a given centrality. For High p_T particles, the production cross section is normally given by pQCD,

$$d\sigma \propto f^A(x_1) \otimes f^B(x_2) \otimes D_h(z) \otimes d\hat{\sigma}_{x_1+x_2} \tag{2}$$

where $f^i(x)$ is the parton distribution function of the incoming beam particle $i = A, B$, $D_h(z)$ is the fragmentation function and $d\hat{\sigma}$ is the partonic cross section.

Nuclear modifications of the initial parton distributions, such as (anti)shadowing[2], and variations in parton energy loss and multiple scattering could lead to a change in

† For the full PHENIX Collaboration author list and acknowledgment, see Appendix "Collaboration" of this volume.

R_{CP}. It is also important to note that particles produced in dAu collisions at large forward (or backward) rapidity are from partons with small (or large) x in Au nuclei, $x = \frac{M_T}{\sqrt{s}} e^{-y}$, with M_T the mass scale of the partonic process. Without nuclear effects, the number of particles produced in hard scatterings would scale with the number of binary collisions and $R_{CP}(p_T, y)$ would be unity, independent of the rapidity and centrality. Thus R_{CP} provides a good experimental tool to study non-trivial nuclear effects in heavy ion collisions. Our current understanding of nuclear effects at large rapidity in high energy heavy ion collisions is very limited both experimentally and theoretically. Several existing models give quite different predictions[3] on particle production at large rapidity - from strong enhancement to strong suppression.

Besides the difference in the initial state x values, it is also important to realize that in d-Au collisions at RHIC, particles detected in the forward and backward directions by the PHENIX muon detector in the CM frame (LAB frame at RHIC) have very different kinematics in the Au rest frame (from 10^0GeV, backward, to 10^3GeV, forward) thus the interactions of the produced particles with the (cold) Au nuclear medium, right after the hard scattering, could be very different in these two kinematic regions[**?**]. Understanding such effects is important to allow disentanglement of initial and final state effects in AuAu collisions.

2. Hadron measurement with the PHENIX Muon Spectrometers

The two PHENIX muon spectrometers cover the pseudo-rapidity ranges $1.2 < \eta < 2.4$ and $-2.2 < \eta < -1.2$ with excellent momentum resolution and muon identification[4]. In front of each muon spectrometer, there is a $5\lambda_I$ (nuclear interaction length) thick nose cone absorber that is about 40cm away from the central collision point. The excellent capability for muon measurement has already been demonstrated in recently published $J/\psi \rightarrow \mu^+\mu^-$ measurements[5]. Here we discuss the novel techniques we developed recently to extend the capability of the muon spectrometers to include hadron measurements at large rapidity.

A hadron can decay into a muon before the nose cone absorber, the muon is then measured by the muon spectrometer. This method is widely used in high energy experiments to measure heavy flavor production through their (semi)leptonic decays. We extend this method to measure light meson decays, such as $\pi^\pm \rightarrow \mu^\pm + \nu$. In PHENIX, due to the finite distance from the collision vertex to the nose cone absorber, charged pions and kaons from the collisions have a chance to decay before they reach the absorber, with the decay probability P_{decay} given by,

$$P_{decay}(p, L) = 1 - \exp(-\frac{L \cdot m}{\tau \cdot p}) \simeq \frac{L \cdot m}{\tau \cdot p} \quad (3)$$

where L is the distance to the absorber; p, m and τ are the momentum, mass and proper lifetime of the particle. Thus, collisions that occurred far from the absorber will be more likely to have muons from light meson decays than those that happened close to the absorber. Figure 1 shows the normalized collision vertex distribution from events with

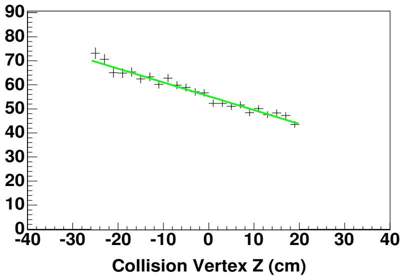

Figure 1. Normalized collision vertex distribution from events with forward muons($p_Z > 0$).

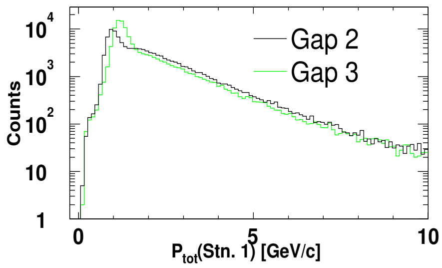

Figure 2. Momentum distributions of tracks stopped at various muID absorber layers.

forward muons in dAu collisions. The large slope indicates a significant fraction of muons are from pion and kaon decays. By studying the event collision vertex distribution, muons from light meson decays are extracted statistically. For heavy hadrons, due to their very short proper decay lengths, $\exp(-\frac{L \cdot m}{\tau \cdot p}) << 1$, the collision vertex dependence is minimal.

In addition to muons from hadron decays, about 1% of hadrons from the collisions can punch through the first nose cone absorber, sail through the muon tracking system and finally be absorbed inside the muon identification system. Figure 2 shows the momentum distributions of tracks stopped in the gap-2 and gap-3 muID absorber layers. The sharp peaks near $P_{tot} \sim 1.5$GeV are due to stopped low energy muons, as they lose all of their energy by ionization in the absorber. In the high momentum region, $P_{tot} > 2$GeV, most of the tracks are stopped hadrons. A detailed MC simulation shows that a momentum cut $P_{tot} > 2$GeV can reject most of the soft muons and yield about 97% pure hadrons in the sample.

3. Results

Hadrons measured with the methods described above are used to study the centrality and rapidity dependence of R_{CP}. In the first case, most of the muons are from an about equal mixture of charged pion and kaon decays; in the second case, the tagged hadrons are from a mixture of mesons and baryons, with relative fractions modulated by their nuclear interactions with the nose cone absorbers. Minimum $p_T > 1.5$GeV and $p_T > 1.0$GeV cuts are used in the above analyses to reject soft processes, respectively. Figures 3 and 4 show the centrality dependent R_{CP} measured with muons from light meson decays and punch-through hadrons. The reference peripheral bin is from $60-88\%$ centrality collisions. R_{CP} results are shown in $0-20\%$, $20-40\%$ and $40-60\%$ centrality bins. The dominant errors are from statistics and the uncertainties in the determination of the number of binary collisions $< N_{coll} >$ in a given centrality bin, which is shown as a block error bar in each plot at $R_{CP} = 1$. We have observed a suppression in very central collisions relative to the peripheral one in the forward rapidity, and an enhancement in

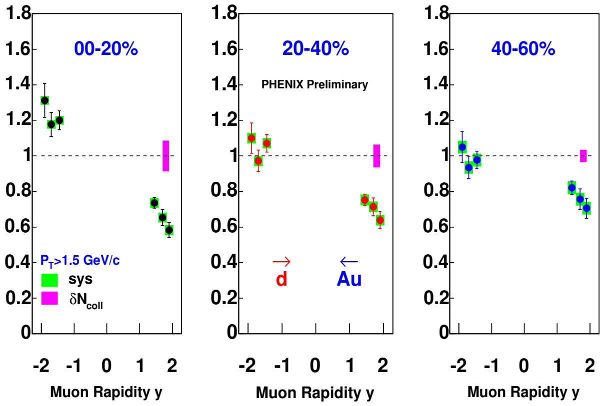

Figure 3. R_{CP} measured with muons from light meson decays.

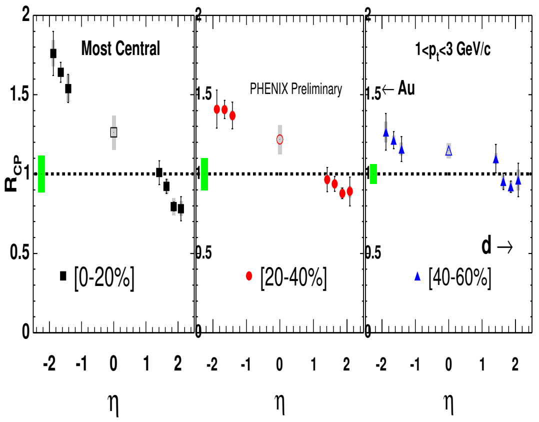

Figure 4. R_{CP} from punch-through hadrons.

the backward rapidity. For a typical $P_T \sim 1.5$GeV hadron, the x value probed in Au at the very forward rapidity $y \sim 2$ is estimated as $x_{Au} \sim \frac{2\times p_T}{\sqrt{s_{NN}}}e^{-y} = 2\times 10^{-3}$; at the very backward rapidity $y \sim -2$, $x_{Au} \sim \frac{2\times p_T}{\sqrt{s_{NN}}}e^{-y} = 1\times 10^{-1}$.

4. Summary and Outlook

We have presented R_{CP} measurements with hadrons in the forward and backward rapidities in dAu collisions at RHIC. BRAHMS experiment has also reported similar results at forward rapidity in this conference.[6] The preliminary results seem qualitatively consistent with parton shadowing/saturation picture in small x and antishadowing/Cronin effect in large x inside the Au nucleus. It will be very interesting to see what happens to Drell-Yan and open charm R_{CP} as we have observed a very similar effect in J/ψ production in d-Au collisions.[7] In addition to R_{CP}, measurements of R_{dA} (which is normalized with pp data rather than peripheral dAu data) will be important to completely understand the absolute nuclear effects, such as suppression and enhancement, since the most peripheral $60-88\%$ bin used to calculate R_{CP} in this analysis could still be significantly different from a minimum bias *pp* reference.

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