PROCEEDINGS OF SCIENCE

Open Heavy Flavor Results from PHENIX

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Due to their large mass, heavy quarks are produced in the earliest stages of the collision and will, therefore, experience the full evolution of the system. Leptons resulting from heavy flavor decay are an important tool to probe the hot and dense matter created in nucleus-nucleus collisions at the Relativistic Heavy Ion Collider (RHIC). PHENIX is capable of measuring electrons in the central rapidity region ($|y| < 0.35$) and muons in the forward rapidity region ($1.2 < |y| < 2.2$). PHENIX has multiple cross section measurements in $p+p$ collisions at 200 and 500 GeV. These measurements provide a test of perturbative quantum chromodynamics (pQCD) theory in additional to a crucial baseline to study the hot and cold nuclear matter effects present in heavy ion collisions. Similar measurements in $d+Au$ allow access to initial state cold nuclear matter effects. Modification of heavy flavor production in heavy ion collisions ($Au+Au$ and $Cu+Cu$) is beyond that expected from cold nuclear matter effects alone.

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1. Introduction

The primary goal of the RHIC program is to study the quark gluon plasma (QGP) created in heavy ion collisions. Heavy quarks can be used to probe medium properties. The large mass of the charm and bottom quark ($m_c \sim 1.3$ GeV and $m_b \sim 4.2$ GeV) require that they be produced early in the collision. Leptons from heavy flavor decay are particularly useful to study because once created they will not interact strongly, thus carrying information about the conditions when they were created.

The modification of heavy flavor leptons as a function of p_T can be described by the parameter R_{AA} which compares the yield of heavy flavor leptons in nucleus-nucleus collisions to the (scaled) yield in $p+p$. The nuclear modification factor is given by:

$$R_{AA} = \frac{dN_{AA}/dp_T}{< N_{coll} > \times dN_{pp}/dp_T} \tag{1.1}$$

where dN_{AA}/dp_T is the yield of leptons from heavy flavor decay in heavy ion or $d+Au$ collisions, dN_{pp}/dp_T is the yield in $p+p$ collisions, and $< N_{coll} >$ is the average number of binary collisions. If a suitable $p+p$ reference is not available, comparing central to peripheral centrality bins can provide a similar comparison:

$$R_{CP} = \frac{\frac{dN_{AA}}{<N_{coll}>\times dp_T}(central)}{\frac{dN_{AA}}{<N_{coll}>\times dp_T}(peripheral)}. \tag{1.2}$$

A R_{AA} or R_{CP} of 1 indicates no medium effects (or balancing effects), whereas a value not equal to 1 indicated suppression (< 1) or enhancement (> 1).

2. Experiment

The PHENIX detector [1] consists of two central arm spectrometers and two muon arm spectrometers. The central arms are designed to measure hadrons, photons, and electrons in the rapidity region $y < 0.35$ and cover π in azimuth. The muon arms are designed to measure muons in the forward rapidity region $1.2 < |y| < 2.2$ and cover 2π in azimuth. Most recently a muon piston calorimeter and silicon vertex detectors were added.

At PHENIX, open heavy flavor are measured indirectly through their semileptonic decay channel. Electrons are measured at mid-rapidity and muons at forward/backward rapidity. The method currently used for measuring heavy quarks does not allow for separation of charm and bottom.

3. Results

3.1 $p+p$

Precise heavy flavor measurements in $p+p$ collisions are necessary as they provide a crucial baseline to study the modification of heavy flavor in heavy ion collisions. These measurements can also be used as a test of pQCD theory. PHENIX has both differential cross section measurements for heavy flavor and total cross section measurements for $c\bar{c}$ and $b\bar{b}$ production. Figure 1 shows the

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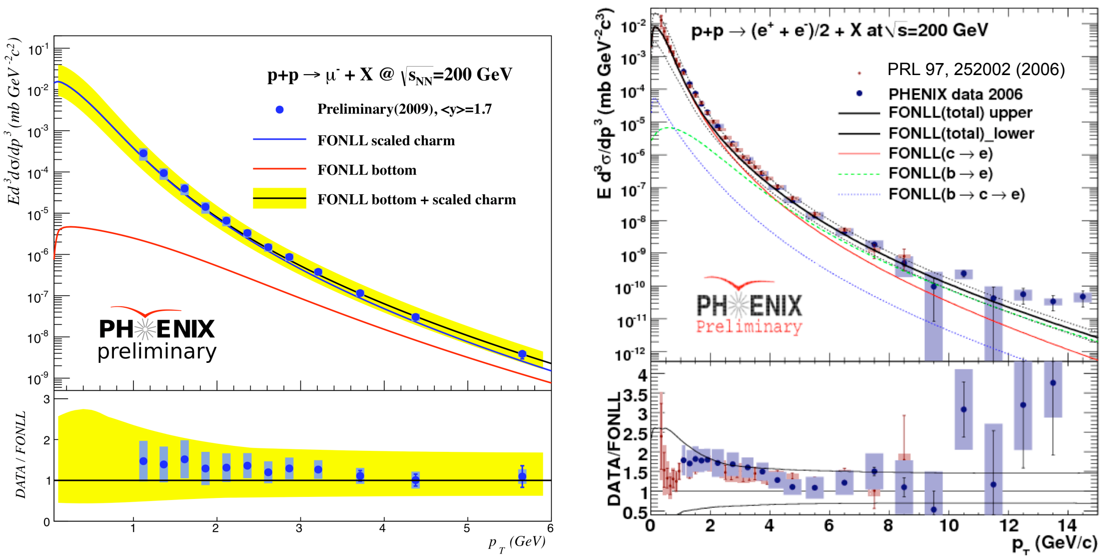

Figure 1: Differential cross section vs. p_T for single muons (left) and single electrons (right). All data is for $p+p$ collisions at $\sqrt{s} = 200$ GeV.

differential cross section vs. p_T for single muons in the forward rapidity region (left) and single electrons in the central rapidity region (right). Recent PHENIX data from 2009 has been used to extend the rapidity range of forward muon results beyond those previously reported [2]. Additionally, higher statistics data from 2006 has been used to extend the p_T range of the single electron measurements up to 14 GeV/c. The 2006 data is in good agreement with that from 2005 [3].

PHENIX has also measured $\sigma_{c\bar{c}}$ in $p+p$ collisions at $\sqrt{s}$ = 200 GeV through multiple decay channels. For bottom production, PHENIX has $\sigma_{b\bar{b}}$ measurements at $\sqrt{s}$ = 200 GeV and, most recently, $\sqrt{s}$ = 500 GeV. PHENIX measurements are in agreement with NLO pQCD.

3.2 $d+Au$

At RHIC energies, heavy quarks are predominately produced through gluon fusion. Their production is, thus, affected by the gluon density in the nucleus. Using leptons from open heavy flavor decay allows access to initial state effects such as gluon shadowing/anti-shadowing and gluon saturation at low-x without the final state breakup effects that affect quarkonia. It is important to understand cold nuclear matter (CNM) effects as these will be present along with hot nuclear matter (HNM) effects in heavy ion collisions. The nuclear modification of heavy flavor leptons in $d+Au$ collisions can be used to probe CNM properties as no QGP is expected to form.

Figure 2 (left) shows the R_{dA} of electrons from heavy flavor decay [4]. In the most peripheral bins (60-80% centrality) there appears to be no modification. However, in the most central collisions (0-20% centrality) an enhancement is observed which is similar to Cronin enhancement in hadron production. Preliminary results for the nuclear modification of single muons is plotted in terms of R_{CP} and shown in Fig. 2 (right). In the *Au*-going direction (forward rapidity) there is enhancement similar to the central rapidity region and in the *d*-going direction (backward rapidity) suppression is seen. This observation is consisted with what is expected based on the modification

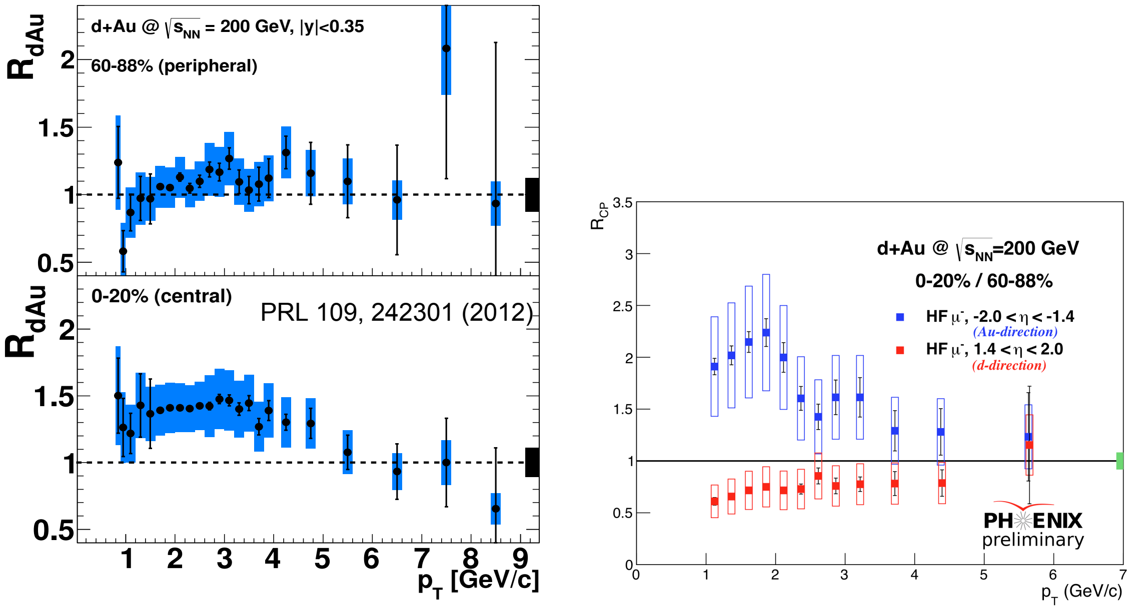

Figure 2: R_{dA} for electrons [4] (left) and R_{CP} for muons (right) in $d+Au$ collisions.

of gluon parton distribution function in the Au nucleus, as the PHENIX detector covers the Bjorken x regions of shadowing (forward rapidity), suppression-enhancement transition (central rapidity), and anti-shadowing (backward rapidity).

3.3 Heavy Ion

At sufficiently high densities, such as those present in heavy ion collisions, a quark gluon plasma is expected to form. Single leptons from heavy flavor decay can be used to probe the medium properties. PHENIX has results for nuclear modification of leptons from heavy flavor decay in $Au+Au$ and $Cu+Cu$ collisions at $\sqrt{s_{NN}}$ = 200 GeV. These two collision systems provide environments to explore hot nuclear matter (HNM) in mediums of different densities. The less dense $Cu+Cu$ collisions provide a region of overlap in $< N_{coll} >$ between $d+Au$ and $Au+Au$.

Figure 3 (left) shows the R_{AA} of muons and electrons in the most central (0-20%) $Cu+Cu$ collisions. A suppression is observed for muons at forward/backward rapidity and no suppression is seen for electrons at mid-rapidity. In heavy ion collisions, nuclear modification is due to a combination of HNM and CNM effects. The observed R_{AA} of heavy flavor electrons in $Cu+Cu$ collisions is due to compensating effects of HNM and CNM while heavy flavor muons in the forward/backward rapidity region experience suppression from both CNM and HNM effects.

As the density of the collision system and $< N_{coll} >$ increases so do the effects of HNM on the heavy flavor leptons. The R_{AA} of single electrons in $\sqrt{s_{NN}}$ = 200 GeV $Au+Au$ collisions is shown in Fig. 3 (right). The data is inclusive of all centralities. For $p_T > 1.5$ GeV/c the electrons from heavy flavor decay show a large suppression [5]. As a comparison, the R_{dA} of heavy flavor electrons in $d+Au$ collisions at $\sqrt{s_{NN}}$ = 200 GeV is also plotted for all centrality bins. Comparisons between the R_{AA} and R_{dA} imply that the suppression seen in $Au+Au$ is due to final state HNM effects.

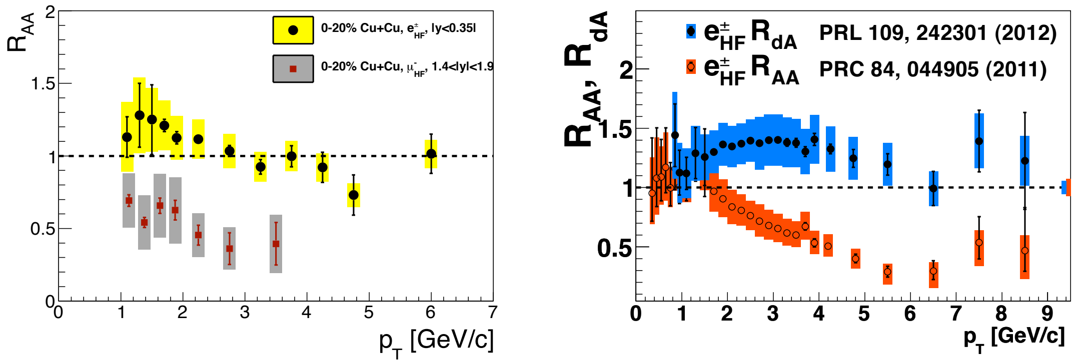

Figure 3: R_{AA} for electrons and muons [2] in the most central (0-20%) $Cu+Cu$ collisions (left) and electrons in $Au+Au$ collisions [5] (right). For comparison, the R_{dA} of electron is shown in the right plot.

4. Conclusions

PHENIX has multiple cross section measurements for heavy flavor production in $p+p$ collisions which are used as the baseline to study nuclear modification. To understand CNM effects, the nuclear modification of leptons from heavy flavor decays in $d+Au$ were studied. Single lepton results show some rapidity dependent modification: enhancement in the central and backward rapidity regions and suppression in the forward rapidity region. Heavy ion results show suppression beyond that expected from CNM effects implying that the suppression is due to energy loss in the QGP rather than initial state effects.

To fully understand the energy loss mechanisms of heavy quarks in the QGP, it is necessary to separate the contributions from charm and bottom. PHENIX has recently installed two silicon vertex detectors covering central and forward rapidities. These detectors will allow for heavy flavor separation based on the leptons displaced vertex.

References

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