Heavy Flavor Production at PHENIX at RHIC

Xiaorong Wang for PHENIX collaboration

New Mexico State University, Las Cruces, NM 88003, USA
Hua-zhong Normal University, Wuhan 430079, P.R. China

Abstract.
A study of heavy flavor production in different collision systems in various kinematic regions presents an opportunity to probe cold nuclear medium and hot dense matter effects. Results from the PHENIX experiment on $J/\psi$ and open charm production in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}=200$ GeV are presented. The data show strong $J/\psi$ suppression in central AA collisions, similar to NA50 results, and strong suppression in high $p_T$ open charm production. The $J/\psi$ production in Au+Au and d+Au collisions is compared to understand the cold nuclear medium effects. The data show significant cold nuclear effects in charm production in d+Au collisions at forward and backward rapidity ranges.

Keywords: Heavy Flavor, Nuclear Effect, High Density matter
PACS: 25.75.-q

INTRODUCTION

Heavy flavor is a sensitive probe of the gluon structure function in the nucleon and its modification in nuclear matter. Charm quarks are believed to be mostly created from initial gluon fusion in hadronic collisions. Since they are massive, heavy flavor hadrons are proposed to be ideal probes to study the early stage dynamics in heavy-ion collisions.

$J/\psi$ and open charm production are two of the most important hard probes of the hot dense matter created in Au+Au collisions. It is also necessary to understand their production in the cold nuclear medium in d+Au collisions as a reference in their production in Au+Au collisions. Since the initial formation of both open and closed charm is sensitive to initial gluon densities, then gluon structure functions, shadowing or anti-shadowing and initial state energy loss will all affect their production. During the hadronization, the $J/\psi$ production mechanism is different from that of open charm. In the final state, the $J/\psi$ can be disassociated or absorbed, but for open charm, the main nuclear medium effect is final state multiple scattering and energy loss.

The PHENIX detector is well-suited for lepton measurements. At mid-rapidity a Ring Image Cherenkov Detector (RICH) and an electromagnetic calorimeters are used to identify electrons. The PHENIX moun tracker and muon identifier work together to reconstruct muons at forward and backward rapidities. One should note here that we measure non-photonic electrons and prompt muons to study open heavy flavor semi-leptonic decay, but we can not separate charm and bottom contributions. The PHENIX beam-beam counter provides a centrality and collision vertex measurement.

The PHENIX experiment[1] has measured $J/\psi$ and open charm production through observation of dilepton and semi-leptonic decays respectively, in three rapidity ranges with the PHENIX muon spectrometers and central arms, covering rapidity range of
The nuclear modification factors is defined as the particle yield per nucleon-nucleon collision relative to the yield in p+p collisions. The PHENIX collaboration has measured the $J/\psi$ nuclear modification factor for d+Au [2], Cu+Cu and Au+Au collisions. Figure 1a shows the nuclear modification factor for d+Au collisions vs rapidity. A significant deviation from unity is seen at the forward rapidity. Theory curves show the cold nuclear medium calculations with shadowing and absorption present. The current d+Au data probably only constrain absorption to $\sigma_{\text{ABS}} \sim 0$ – 3 mb. Comparison with theoretical calculations [3] shows that a modest amount of absorption with a modest shadowing scheme such as the EKS [4] prescription, can describe d+Au data.

In the hot dense matter in Au+Au collisions (Figure 1b, blue and red solid squares), nuclear modification factor of $J/\psi$ shows strong suppression at most central Au+Au collisions. Calculations from same model [5] to extrapolate such effects seen in d+Au to Au+Au are presented on figure 1b. The curves show $R_{AA}$ as a function of $N_{\text{part}}$. They account for shadowing (following the EKS prescription) and nuclear absorption $\sigma_{\text{ABS}} = 3mb$ (solid lines for $y =0$ and dashed lines for $y=2$). The theoretical curves gives an idea of cold nuclear matter effects on the $J/\psi$ production in A+A collisions. For the most central Au+Au collisions measurements depart from the stronger nuclear effects predictions (3 mb) suggesting effects beyond cold nuclear matter are involved. For now, at least three classes of models, Detailed transport [6], sequential melting [7] and recombination models [8]–[10] exist that can roughly accommodate the amount of
anomalous suppression seen in our most central preliminary results.

OPEN CHARM PRODUCTION IN AU+AU AND D+AU

PHENIX studies of open heavy flavor are conducted via observation of semi-leptonic decays. PHENIX has measured the $p_T$ spectra of non-photonic electrons, $(e^+ + e^-)/2$ at mid-rapidity ($|\eta| < 0.35$) up to $p_T = 5$ GeV/c in d+Au and in Au+Au collisions\(^{11}\).

The non-photonic single electron production at middle rapidity follows binary collision scaling within experimental uncertainty in d+Au collisions (see Figure 2a). Figure 2b shows $R_{AuAu}$ from the most central collisions compared to theoretical predictions. In order to describe the data, large values of the transport coefficient or gluon density have been assumed. In addition, the bottom quark to charm quark ratio is not well known. To gain a better theoretical understanding of the strong medium modification observed, the charm and bottom quark signals need to be disentangled.

However in the forward and backward direction of d+Au collisions, we probe different $x$ ranges which are sensitive to cold nuclear effects such as parton shadowing, color glass condensate, initial state energy loss, and coherent multiple scattering in final state interactions. PHENIX has measured prompt single muon productions in d+Au collisions.

Figure 3 shows the nuclear modification factor $R_{dAu}$ of prompt muons at forward and backward rapidities. Suppression is observed in the forward direction, which is consistent with CGC\(^{13}\) and power correction pictures. The enhancement at the backward direction needs more theoretical investigation as well as reduced experimental errors. Anti-shadowing and recombination could lead to such enhancement.
FIGURE 3. Invariant spectra (left) and nuclear modification factor of prompt muons (right) in d+Au collisions. The theoretical curves are from a power correction model at $\eta = 1.25$ and 2.5 [14].

SUMMARY

PHENIX preliminary $J/\psi$ results show a large amount of suppression, which is about a factor of three. However, its interpretation is not clear. First, the amount of normal, cold nuclear matter suppression is not precisely defined and demands better d+Au reference. Nevertheless, the observed suppression in Au+Au seems to exceed the maximum suppression permitted by cold nuclear matter effects. Three classes of models that raise the number of surviving $J/\psi$s were presented. They all suppose the formation of a QGP.

Open charm production in d+Au collisions in the forward and backward directions suggests significant cold nuclear medium effects. The open charm production in Au+Au collisions favors the models with strong coupling and large energy loss. To understand the energy loss mechanism, we need to separate the charm and beauty contributions.

REFERENCES

1. K. Adcox et al., Nucl. Instrum. Methods A499, 469 (2003)
2. S.S. Adler et. al, PHENIX collaborations, Phys. Rev. Lett 96, 012304 (2006)
3. R. Klein and R. Vogt, Phys. Rev. Lett. 91, (2003) 142301.
4. K. J. Eskola, V. J. Kolhinen, and C. A. Salgado, Eur. Phys. J. C9 (1999) 61.
5. R. Vogt, [nucl-th/0507027]
6. X.L. Zhu et al., Phys. Lett. B607 (2005) 107-114
7. F. Karsch et al., Phys. Lett. B637 (2006) 75-80.
8. E.L. Bratkovskaya et al., Phys. Rev. C69 (2004) 054903;
9. A. Andronic et al., Phys. Lett. B571 (2003) 36-44;
10. R.L. Thews and M.L. Mangano, Phys. Rev. C73 (2006) 014904.
11. S. Butsyk for PHENIX collaborations, [nucl-ex/0510010]
12. N. Armesto, S. Dainese, C. Salgado, and U. Wiedemann, Phys. Rev. D71, 054027 (2005).
13. L. McLerran and R Venugopalan, Phys. Rev. D49, 2233(1994); Phys. Rev. D49 3352(1994)
14. J. Qiu, I. Vitev, Phys.Lett. B632, (2006)507-511