Open Heavy Flavor Measurements at PHENIX

Tatia Engelmore for the PHENIX Collaboration

Columbia University, New York, New York 10027 and Nevis Laboratories, Irvington, New York 10533, USA

Abstract. Recent measurements at RHIC have shown leptons from open heavy flavor decay to be strongly suppressed in heavy ion collisions compared to binary scaling from measurements in *p*+*p* collisions. At PHENIX, this suppression has been seen in single electrons from heavy flavor decays in Au+Au collisions, and also in single muons in Cu+Cu collisions. To better understand these results it is important to study open heavy flavor spectra along with correlations in the same manner in which light hadrons have been studied at RHIC.

The latest PHENIX studies include heavy flavor angular correlations in *p*+*p*, *d*+Au, and Au+Au collisions. This full range of measurements will allow us to disentangle effects due to cold nuclear matter versus those resulting from the hot medium created in heavy ion collisions. The correlations will also help us to understand heavy flavor production mechanisms. Several studies of electron-hadron correlations have been made, the first involving mass correlations that measure the ratio of bottom to total heavy flavor production in *p*+*p* collisions. Additionally, *e*-h correlations in azimuthal angle have been studied in heavy ion collisions, allowing us to explore the modification of jets containing heavy flavor. Electron-muon azimuthal angular correlations, in which each lepton is measured in a different rapidity window, are a very clean signal of heavy flavor quark formation. Measurements in *p*+*p* collisions could help us to understand heavy quark production mechanisms, while the study of these correlations in *d*+Au collisions will enable us to understand initial state effects like gluon saturation or energy loss that occur at low x. PHENIX heavy flavor measurements will soon be enhanced with the addition of two silicon vertex detectors, the VTX in the central rapidity region and the FVTX in the forward rapidity region. These will allow precise identification of heavy flavor electrons and muons via tagging of displaced vertices. In this talk we will compare these measurements, and their theoretical implications will be discussed.

Keywords: Quark gluon plasma, heavy flavor, single electron, single muon, electron-hadron, electron-muon
PACS: 25.75.Cj

INTRODUCTION

Open heavy flavor is currently a very active topic of research at PHENIX. Charm production is hard to quantify, because the charm quark's medium-size mass places it at the boundary of the regime where pQCD calculations apply. Charm seems to behave unexpectedly while traversing the hot medium created in a heavy ion collision. The single electron spectra measured by both PHENIX and STAR shows a large degree of suppression in Au+Au collisions, though heavy flavor was originally thought to lose little energy due to gluon radiation [1] [2] [3]. Now various theory descriptions of charm propagation through a medium have been proposed, but it is unclear which best describes the data. The ratio of charm to bottom is an important quantity to have because it will allow us to separate the level of suppression due to charm versus that due to bottom in the single lepton results. The *c*-to-*b* ratio is also calculable with pQCD, though it is subject to large error bars, which is why precise experimental measures are important.

Open heavy flavor has been shown to have several other interesting properties. A significant amount of elliptic flow has been measured, which is surprising given the large mass of the charm. The shape modification of charm jets in the medium has also been studied by using azimuthal correlations. Hints of away-side broadening have been seen in *e*-*h* correlations in Au+Au and in e-μ correlations in *d*+Au, but low statistics mean that further measurements are required to reach a conclusion. Also, the study of open heavy flavor is of great benefit to understanding J/Ψ suppression in heavy ion collisions. It can help determine how much of the suppression is due to shadowing, which also affects open heavy flavor, versus how much is due to breakup in the medium, which only affects charmonium. In the following proceedings we will summarize the baseline measurements made in *p*+*p* collisions at PHENIX to date, as well as the heavy ion results.

OPEN HEAVY FLAVOR IN *p*+*p* COLLISIONS

PHENIX primarily measures heavy flavor through single leptons, which are the products of *D* and *B* meson decay. Electrons are measured at mid-rapidity, $|y| < 0.35$ [4]. While PHENIX is very good at precisely identifying electrons, there is inevitable background due to photonic sources (mostly π^0 decay and photon conversions) and other meson decays. To remove these backgrounds, two complementary subtraction methods are used: the cocktail method, and the converter method. The cocktail is composed of simulated background sources normalized to the spectra measured by PHENIX, which are then subtracted. The converter method uses extra material added around the beam pipe during a few runs to increase the yield of photonic electrons by a known amount. This allows the photonic yield without the extra material to be extrapolated. These two methods agree well with each other. After background subtraction, the heavy flavor electron yield is consistent with NLO predictions.

Single muons have been measured at forward and backward rapidity, $< |y| >= 1.65$ [5]. While the PHENIX muon detectors absorb the majority of hadrons produced in the forward regions, some do contribute to muon backgrounds. To eliminate these, a hadronic muon cocktail was created, similar to that used for the electron analysis. The results lie above the NLO predicted spectrum, but the difference has decreased relative to the previously published results. Both the muon and electron results are shown in Fig. 1.

It is impossible to tell which leptons are from charm and which are from bottom, because PHENIX is not yet able to measure precisely the decay vertex position. This will change, though, as soon as data is analyzed using the new silicon vertex upgrade detectors (see below). In the meantime, a technique using *e*-*K* correlations has been used to measure the ratio of charm to bottom for electrons. The invariant mass of *e*-*K* pairs from the same jet was found, and compared with predictions from simulations [6]. The ratio was found by comparing the mass distributions of pairs from bottom decay to those from charm decay. The fraction of bottom was found to increase with increasing p_T, and is in good agreement with NLO predictions.

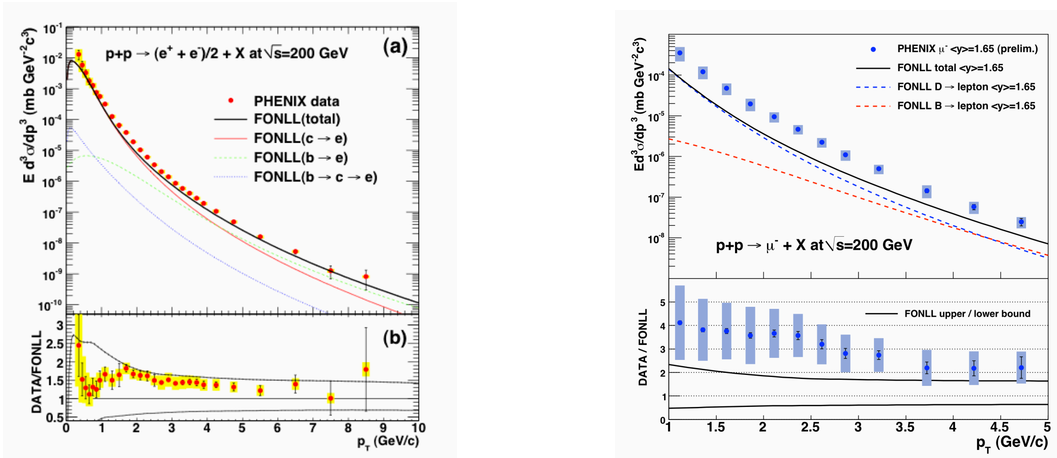

FIGURE 1. On the left, PHENIX single electron cross section as a function of p_T along with a comparison to Fixed-Order Next-to-Leading Logarithm (FONLL) predictions for both charm and bottom decay channels. Right, a similar plot for single muons.

OPEN HEAVY FLAVOR IN HEAVY ION COLLISIONS

Single electrons in Au+Au collisions have been found to be suppressed relative to the p+p baseline, by an amount similar to that of pions [3]. The effect is largest at high p_T, which is even more surprising given that bottom dominates in that momentum range. Similar suppression at high p_T was found for forward rapidity muons in Cu+Cu collisions. Because the medium is less dense for copper vs. gold collisions, the amount of suppression hints at the importance of initial state shadowing effects. The level of suppression for both electrons and muons is shown in Fig. 2. Heavy flavor electrons also exhibit elliptic flow, meaning that heavy quarks interact strongly with the medium.

Because heavy quarks have been shown to interact with the medium as much as light quarks, the angular distributions of heavy flavor jets may also be modified. Charm dijets may be identified using electron-hadron correlations, in which one D decays to an electron and the other decays to an unidentified hadron. Some suppression of the away-side jet is evident from e-h correlations in Au+Au collisions [7]. Another way to study charm jets is to use e-μ correlations, where the electron and muon result from back-to-back D mesons. This signal has lower background, though also a smaller branching ratio, than the e-h signal. Correlated e-μ pairs in d+Au collisions are shown to be suppressed relative to those in p+p collisions, hinting at the effects of cold nuclear matter on charm production. Both of these measurements have large associated errors, however, making it difficult to draw conclusions.

FUTURE OF OPEN HEAVY FLAVOR AT PHENIX

PHENIX will soon be able to tag electrons and muons as coming from either charm or bottom jets using the new vertex detector upgrades. These consist of a silicon vertex detector in the midrapidity region ($|\eta| < 1.2$) and the forward vertex detectors at foward

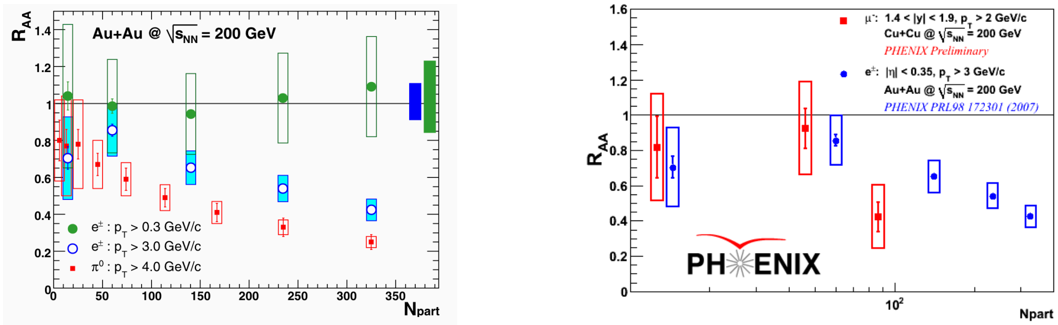

FIGURE 2. Left, a comparison of the nuclear modification factor R_{AA} for inclusive electrons (green) and high p_T electrons (blue) vs. pions (red). Right, R_{AA} for forward rapidity muons in Cu+Cu collisions (red) vs. high p_T electrons (blue). In both plots R_{AA} is shown as a function of the number of participants, N_{part}.

and backward rapidity ($1.2 < |\eta| < 2.4$). The goal of both detectors it to measure the displaced vertex of an electron or muon, measuring the distance the parent meson traveled before decaying and thereby indentifying it as either a B or a D. The silicon vertex detector was installed for the 2011 run, while the forward vertex detector is due to be installed for the 2012 run.

CONCLUSION

In summary, we have presented recent results for heavy flavor measurements at PHENIX in a variety of collision systems. A suppression in forward single muons in Cu+Cu collisions agrees with the suppression seen in central Au+Au collisions. In order to better understand the energy loss of charm versus that of bottom, the c-to-b ratio has been measured in p+p collisions. Also, slight evidence of heavy flavor jet shape modification has been seen in e-h and e-μ correlations. Open heavy flavor measurements are very important for better understanding the full range of PHENIX results. The suppression and flow seen in heavy quarks can help us construct better models for how both heavy and light quarks interact with the medium. With the addition of the new silicon vertex detectors, more precise results will be forthcoming.

REFERENCES

1. Y. Dokshitzer, and D. Kharzeev, *Phys. Lett. B* **519**, 199–206 (2001).
2. B. I. Abelev, et al., *Phys. Rev. Lett.* **98**, 192301 (2007).
3. S. S. Adler, et al., *Phys. Rev. Lett.* **96**, 032301 (2006).
4. A. Adare, et al., *Phys. Rev. Lett.* **97**, 252002 (2006).
5. I. Garishvili, *Nucl. Phys. A* **830**, 625c (2009).
6. A. Adare, et al., *Phys. Rev. Lett.* **103**, 082002 (2009).
7. A. Adare, et al., *Phys. Rev. C* **83**, 044912 (2011).