PHENIX Results on Open Heavy Flavor Production and Flow in $Au + Au$ Collisions at $\sqrt{s_{NN}} = 200$ GeV

Sergey A. Butsyk[a] for the PHENIX Collaboration[*]

[a]Los Alamos National Laboratory,
MS H846 P-25 LANL, Los Alamos, NM, 87545, USA

The paper presents recent PHENIX results for the nuclear modification factor R_{AA} in $Au + Au$ Collisions at $\sqrt{s_{NN}} = 200$ GeV for the electrons originating from semi-leptonic decays of open heavy flavor carrying particles. We also report the results of the azimuthal asymmetry (v_2) measurement for those electrons, which is directly related to the heavy quark elliptic flow.

1. Introduction

Interaction of heavy quarks with hot dense matter, created in heavy ion collisions at RHIC, is a very important probe for understanding the properties of the produced medium. For the case of the light quark, the strong suppression of high transverse momentum pions has been experimentally measured [1,2]. This important result implies that hard scattered partons traveling through the medium created in such collisions experience considerable energy loss. The same effect for heavy quarks is predicted to be smaller than for the light quarks due to a suppression of the phase space for gluon radiation for large masses of the quarks (the so called "dead cone" effect [3]). Due to the interaction of heavy quarks with the medium, heavy flavor particle is expected to exhibit none zero elliptic flow v_2 [4]. The strength of the heavy quark flow in combination with the degree of heavy quark suppression provide crucial information on the nature of the heavy quark interaction with the medium and are therefore very important for the understanding of the medium properties [5].

2. Results on R_{AA}

PHENIX has developed robust and accurate methods [6–8] of measuring the heavy quark production by disentangling the electron contribution from the semi-leptonic decays of the open charm/bottom particles (this contribution is denoted as *"non-photonic"* electrons) from the electrons created from the conventional sources (Dalitz decays of light mesons, photon-conversions in the detector material - referred to as *"photonic"* electrons). The first method, "cocktail" subtraction, is based on simulating the "photonic" electron component with hadron decay generator using published pion results [1,2] as input. The second analysis technique, "converter" subtraction, is based upon direct measurement of

the "photonic" electron contribution from a special set of runs with increased conversion material budget.

Here we present results obtained from the experimental data, collected during the Year 2004 high statistics $Au + Au$ PHENIX run and Year 2003 $p + p$ run. A minimum bias sample of 460×10^6 events was analyzed for $Au + Au$ using the Beam-Beam Counter (BBC) as a trigger source. Compared to the published $Au + Au$ results [7], this gives a factor of 100 statistical improvement, another factor of two due to increased acceptance, and the photonic background was reduced by a factor of two because of the removal of the central vertex detector. For the $p + p$ results, the low p_T part come from the 9.8×10^6 minimum bias events while the high p_T part come from the events firing the level-1 electron trigger (ERT) corresponding effectively to 2.3×10^9 minimum bias events. Comparing to the previous results [8], the luminosity is increased five times and electron acceptance improved by a factor of four. The total material budget of the PHENIX detector corresponded to $X \approx 0.7\% \ X_0$ radiation length from the beam pipe (0.4%) and air (0.3%).

The inclusive electron invariant cross section was corrected for the acceptance and efficiency. The comparison of inclusive electron spectra with the "cocktail" prediction for "photonic" electron background clearly indicated an excess of the electrons. The subtracted "non-photonic" electron yields for different centrality bins are shown in Fig. 1. A fit to the $p + p$ data [9], scaled by corresponding number of binary collisions, is also shown on the plot. One can clearly see that for the most peripheral bin $(60 - 92\%)$ the $Au + Au$ data agrees with the $p + p$ reference and that a high-p_T suppression of the electron yield starts developing towards more central collisions.

To quantify the suppression, we use the nuclear modification factor R_{AA} [2] which is a ratio of the $Au + Au$ invariant electron yield to the $p + p$ cross section, scaled by the nuclear thickness function T_{AA}. R_{AA} for the most central bin $(0 - 10\%$ centrality) is shown on Fig. 2. The systematic error for the ratio was separated in three pieces: the error on T_{AA}, the systematic error on the data and on the $p + p$ reference. The comparison with the published theoretical predictions [10,11] shows that the data supports theories with large transport coefficient ($\hat{q} = 14 GeV^2/c$) or a very high initial gluon density ($dN_g/dy = 3500$). This is a very challenging task for a theory to justify such high values of these parameters, but realistic values of gluon densities ($dN_g/dy = 1000$) significantly underestimate the heavy flavor suppression. It is also very important to mention that in order to make a reasonable theoretical prediction, one needs to include the electron contribution from open charm and open bottom semi-leptonic decays.

3. Results on heavy flavor flow

Azimuthal flow of the open charm/bottom particles can be studied indirectly by disentangling v_2 of the "non-photonic" electrons. Published results from the Year 2002 PHENIX run [12] did not provide enough resolving power to make a clear statement on whether the heavy quarks flow. Using the much higher statistics of the Year 2004 $Au + Au$ run, we obtain much more significant results. The basic idea of the measurement is clearly shown in Fig. 3. The inclusive electron v_2 was measured from the data, then the "photonic" electron v_2 was estimated using an analog of the "converter" subtraction technique
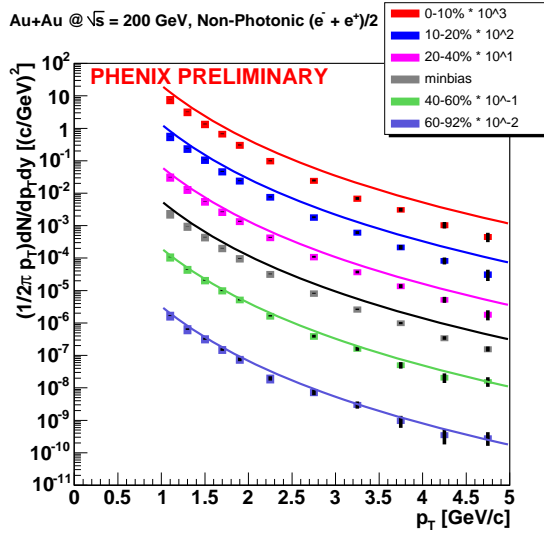
Figure 1. "Non-photonic" electron invariant yield in $Au + Au$ for different centrality bins compared with $p + p$ best fit, scaled by N_{col}.
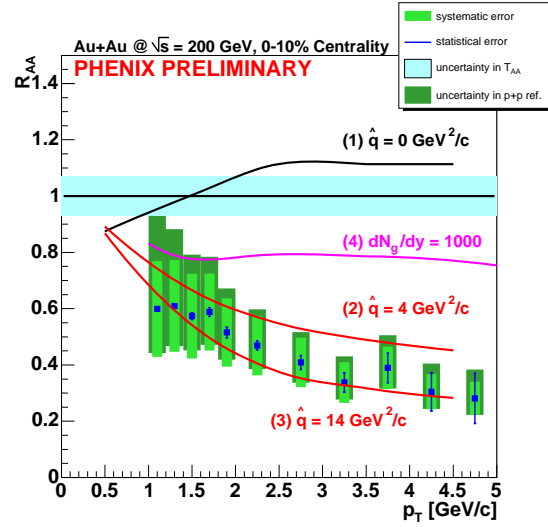

Figure 2. "Non-photonic" electron for 0-10% centrality bin compared with theoretical predictions. Theory curves (1-3) from [10], (4) from [11].

for low p_T and simulated through the "cocktail" from measured flow of the pions for high p_T . Then the flow of "non-photonic" electrons can be calculated, knowing the relative contribution of "non-photonic" electrons in the inclusive spectrum.

Results of this analysis are presented in Fig. 4 in comparison with theoretical calculations for the electron v_2 under the assumptions that the charm quark participates in the collective flow or just picks up the flow from the light quark. One can see that at $p_T < 2$ GeV/c the data are definitely in good agreement with the theoretical predictions in which charm flow is assumed. However in the high p_T region though, the magnitude of the flow saturates and decreases. One possible explanation of this behavior is a contribution of electrons from open bottom decay. The bottom quark is assumed to have a lower v_2 which may cause the large p_T drop of the "non-photonic" electron elliptic flow.

4. Summary and Outlook

During the Year 2003/2004 run the PHENIX experiment accumulated a significant amount of electron data in both $Au + Au$ and $p + p$ colliding systems. New data dramatically improved the statistical significance of the previously published heavy flavor measurements in the single electron channel. Observation of strong suppression of the "non-photonic" electron spectrum developing towards more central collisions is a very important result, providing significant constraint on the theoretical description of heavy-quark energy loss mechanisms. The results of the "non-photonic" electron elliptic flow measurements clearly indicate sizable v_2 of the open charm particles.
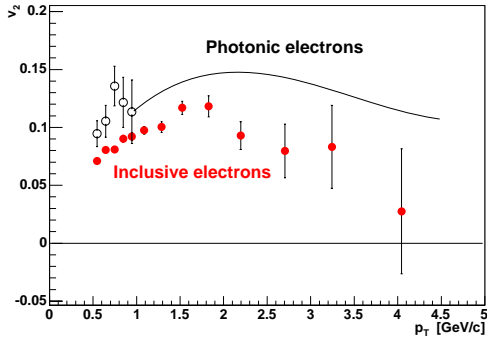
Figure 3. Inclusive electron elliptic flow overlayed with "photonic" electron v_2 estimation.
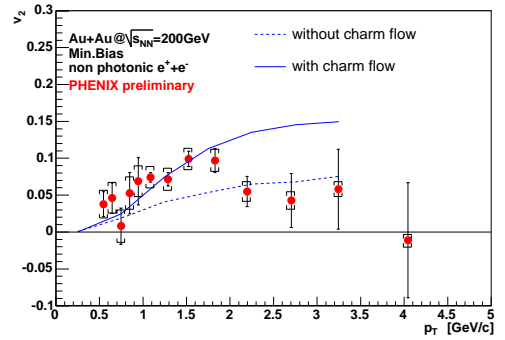

Figure 4. "Non-photonic" electron v_2 compared with theoretical predictions for charm quark flow [13].

REFERENCES

1. K. Adcox *et al.*, Phys. Rev. Lett. **88**, 022301 (2002).
2. S.S. Adler *et al.*, Phys. Rev. Lett. **91**, 072301 (2003).
3. Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B**519**, 199 (2001).
4. S.S. Adler *et al.*, Phys. Rev. Lett. **91**, 182301 (2003).
5. Guy D. Moore, Derek Teaney, hep-ph/0412346.
6. S.S. Adler *et al.*, Phys. Rev. Lett. **88**, 192303 (2002).
7. S.S. Adler *et al.*, Phys. Rev. Lett. **94**, 082301 (2005).
8. S.S. Adler *et al.*, hep-ex/0508034.
9. Y. Kwon, Quark Matter 2005 Parallel Talk.
10. N. Armesto, S. Dainese, C. Salgado, and U. Wiedemann, Phys. Rev. D**71**, 054027 (2005).
11. M. Djordjevic, M. Gyulassy, S. Wicks, Phys. Rev. Lett. **94**, 112301 (2005).
12. S.S. Adler *et al.*, Phys. Rev. C**72**, 024901 (2005).
13. V. Greco, C. M. Ko, R. Rapp, Phys. Lett. B**595**, 202 (2004).