Non-photonic electron-hadron correlations and non-photonic electron $v_2$ at STAR/RHIC

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Abstract

Non-photonic electrons ($p_T > 3$ GeV/c) represent the directions of the parent heavy quarks, and their angular correlations with charged hadrons provide a good tool to study the relative contributions from $D$ and $B$ meson decays in $p+p$ collisions, as well as the flavor-dependence of the energy loss mechanism in $A+A$ collisions. We review the disentanglement of charm and bottom contributions to non-photonic electrons in $p+p$ collisions at $\sqrt{s} = 200$ GeV at RHIC. $B$ decay contribution is approximately 50% at the electron transverse momentum of $p_T > 5$ GeV/c from STAR results. Incorporating the energy loss ($R_{AA}$) information of non-photonic electrons, the result indicates a $B$ meson suppression at high $p_T$ in heavy ion collisions. We also present non-photonic electron-hadron correlations in $d+Au$ collisions as a baseline reference for the investigation of the heavy quark energy loss in $A+A$ collisions. The interactions between heavy quarks and the QCD medium can lead to a non-zero “elliptic flow” parameter ($v_2$) of $D$ and $B$ mesons which can be studied through $v_2$ of non-photonic electrons. Preliminary $v_2$ measurements for non-photonic electrons are shown to be lower than $v_2$ of charged hadrons (or $K^{0}_S$, $\Lambda$) for 200 GeV Au+Au collisions.

Keywords: RHIC, Heavy flavor, Non-photonic electron, Correlation, Elliptic flow

1. Introduction

The “non-photonic” electrons ($e_{non\gamma}$) from semi-leptonic decays of $D$ and $B$ mesons for $p_T$ up to 9 GeV/c in central Au+Au collisions have been observed with yields suppressed to a similar level to that of light quarks at the Relativistic Heavy Ion Collider (RHIC) [1,2]. The suppression was unexpected due to the “dead cone effect”[3]. Fixed-Order-Next-to-Leading-Log (FONLL) pQCD calculations predict that the $B$-decay contribution is significant at and above $p_T$ of 4 – 5 GeV/c, though theoretical uncertainties are large[4]. Measuring the bottom quark contribution to non-photonic electron yields in $p+p$ collisions is important in order to understand the production of heavy quarks and further help to investigate the energy loss of heavy quarks in $A+A$ collisions.

When high-$p_T$ partons lose a significant amount of energy traversing the dense QCD medium created in central Cu+Cu or Au+Au collisions, their azimuthal correlations with low-$p_T$ hadrons are modified, showing a broad or even double-peak structure on the away-side di-hadron correlation [5,6,7]. Non-photonic electrons represent well the directions of the parent $D$ or $B$ mesons when electron $p_T > 3$ GeV/c, and in the opposite direction we expect another heavy quark traversing the medium leaving an imprint on the away-side $e_{non\gamma} - h$ correlation. A similar broadness has been observed on the away-side $e_{non\gamma} - h$ correlations in 200 GeV Au+Au and Cu+Cu collisions [8], and the counterpart study in $d+Au$ collisions will provide a baseline for the energy loss of heavy quarks in the hot and dense medium produced in central $A+A$ collisions.

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Heavy quarks are believed to be produced mostly via initial gluon fusion \[9\] in relativistic heavy ion collisions, and propagation of heavy quarks through the medium is a good probe to study the medium properties. A non-zero \(v_2\) of \(D\) and \(B\) mesons could arise from the interaction between the parent heavy quarks and the medium, and could be approximated by non-photonic electron \(\nu_2\). Thus the \(\nu_2\) measurement of non-photonic electrons will shed light on the extent of the thermalization of the collision system.

2. Analysis and results

In the analysis related to non-photonic electrons, the hadron contamination and the photonic background were removed. The photonic background mainly comes from photon conversions in the detector material and Dalitz decays, dominantly from \(\pi^0\). The photonic electrons were identified by pairing electrons with oppositely charged partner tracks, determining the conversion or decay vertex, and calculating the invariant mass of \(e^+e^-\) [12].

Neglecting contributions from charged baryons, \(e_{\text{non}} R_{AA} [13]\) is given by

\[
R_{AA}^{\text{non}} = (1 - r_B)R_{AA}^{D/B} + r_B R_{AA}^{B/D},
\]

where \(R_{AA}^{D/B}\) (\(R_{AA}^{B/D}\)) is the \(R_{AA}\) for electrons from \(D \,(B, \, \rho)\) mesons [10]. With the current measurement of \(r_B\) and the \(R_{AA}^{\text{non}}\) measurement from PHENIX [14], we picture Eq. [1] in Fig. 3 for \(p_T > 5 \, \text{GeV}/c\), where the solid line represents the most probable values for \(R_{AA}^{\rho/D}\) and \(R_{AA}^{D/B}\), and the dashed lines, the 90\% Confidence Limit. This result indicates that \(B\) meson yields are suppressed at high \(p_T\) in heavy ion collisions. From comparison with model calculations (Fig. 3), we find that those considering suppression of the heavy flavor hadrons due to dissociation (model II [16]) or elastic scattering (model III [17]) processes are consistent with the measurements, while the model considering only b-quark energy loss in the dense medium (model I [15]) is inconsistent with the data.

To study the jet-medium interactions in \(A + A\) collisions, \(d + A\) collisions provide a better baseline reference than \(p + p\) collisions, since “cold nuclear matter” effects [18] such as nuclear absorption and shadowing are accounted for in \(d + A\) collisions. Fig. 4 shows \(e_{\text{non}} - h\) correlations for RHIC run2008 200 GeV \(d + A\) collisions, with the same
Figure 3: Confidence level contours for nuclear modification factor \( R_{AA} \) for electrons from \( D (K^{0}_{S}) \) and \( B (K^{0}_{S}) \) meson decays and determined by combining the \( R_{AA} \) results and the \( r_B \) measurement for \( p_T > 5 \) GeV/c [10]. Three different models of \( R_{AA} \) for \( D \) and \( B \) are described in the text.

Figure 4: The azimuthal angular correlation between non-photonic electrons (3 < \( p_T < 6 \) GeV/c) and hadrons (0.15 < \( p_T < 0.5 \) GeV/c) for 200 GeV \( d + Au \) collisions. The open points are reflections. The left (right) panel shows the correlation before (after) background subtraction, with a dashed fitting curve from PYTHIA expectations on the away side. The error bars are statistical, and the error band around zero shows the systematical uncertainty from ZYAM [10].
$p_T$ ranges for the trigger and associated particles as in Ref[8]. To enhance the statistics, the measured correlations are folded into $[0, \pi]$, and the data points beyond are reflections. On the away side there is a single peak, and the correlation structure after background subtraction can be well described by PYTHIA calculations for $p+p$ collisions, indicating that the impact of cold nuclear matter effects is not prominent on this analysis for these specific $p_T$ ranges.

The left panel of Fig. 5 illustrates the extraction of $v_2(\nonphotonic e)$ via its angular azimuthal correlation with the event plane \cite{20} for 10 – 40% RHIC run2007 200 GeV Au+Au collisions. The retrieved $v_2$ parameter from the fit was corrected with the event plane resolution and for the granularity effect due to the finite $\Delta \phi$ bin width, and the fit error was multiplied by the square root of $\chi^2/\text{ndf}$ to compensate for the fitting quality. The right panel shows the comparison of $v_2$ between $\nonphotonic e$ and charged hadrons ($K^0_S$, $\Lambda$) \cite{21}. With the large statistical errors, $v_2(\nonphotonic e)$ is found to be systematically lower than that of hadrons, $K^0_S$ or $\Lambda$. The feasibility of the heavy flavor tagged correlation analysis has been demonstrated, and we expect a more complete study of this type based on the RHIC run2010 data with much higher statistics and lower detector material budget.

References

[1] A. Adare et al., Phys. Rev. Lett. 98 (2007) 172301.
[2] J. Adams et al., Phys. Rev. Lett. 91 (2003) 172302.
[3] Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B 519 (2001) 199.
[4] M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. 95 (2005) 122001.
[5] J. Adams et al., Phys. Rev. Lett. 95 (2005) 152301.
[6] B.I. Abelev et al., Phys. Rev. Lett. 102 (2009) 052302.
[7] M.M. Aggarwal et al., Phys. Rev. C 82 (2010) 024912.
[8] B. Birnir, Nucl. Phys. A 830 (2009) 849c.
[9] J. Rafelski and B. Muller, Phys. Rev. Lett. 48 (1982) 1066.
[10] M.M. Aggarwal et al., Phys. Rev. Lett. 105 (2010) 202301.
[11] T. Sjotrand, Comput. Phys. Commun. 135 (2001) 238.
[12] J. Adams et al., Phys. Rev. C 70 (2004) 044902.
[13] C. Adler et al., Phys. Rev. Lett. 89 (2002) 202301.
[14] A Adare et al., arXiv:1005.1627.
[15] M. Djordjevic, Phys. Lett. B 632 (2006) 81.
[16] A. Adil and I. Vitev, Phys. Lett. B 649 (2007) 139.
[17] H. van Hees, V. Greco and R. Rapp, Phys. Rev. C 73 (2006) 034913 (private communication).
[18] R. Vogt, Phys. Rev. C 81 (2010) 044903.
[19] J. Adams et al., Phys. Rev. Lett. 95 (2005) 152301.
[20] A.M. Poskanzer and S.A. Voloshin, Phys. Rev. C 58 (1998) 1671.
[21] B.I. Abelev et al., Phys. Rev. C 77 (2008) 54901.