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 beteen 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, Λ) 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 suppresion 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.

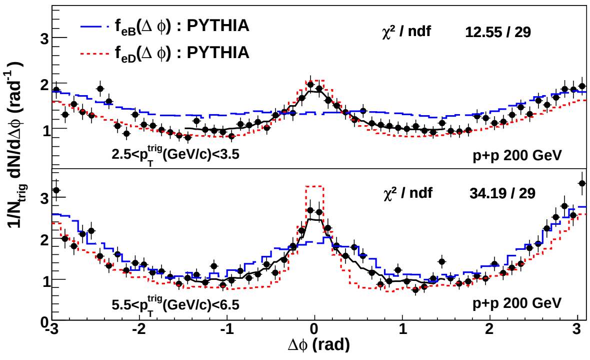

Figure 1: Distributions of the azimuthal angle between non-photonic electrons and charged hadrons normalized per non-photonic electron trigger. The trigger electron has (top) $2.5 < p_T < 3.5$ GeV/c and (bottom) $5.5 < p_T < 6.5$ GeV/c [10]. The curves represent PYTHIA calculations for D (dotted curve) and B (dashed curve) decays [11]. The fit result is shown as the black solid curve.

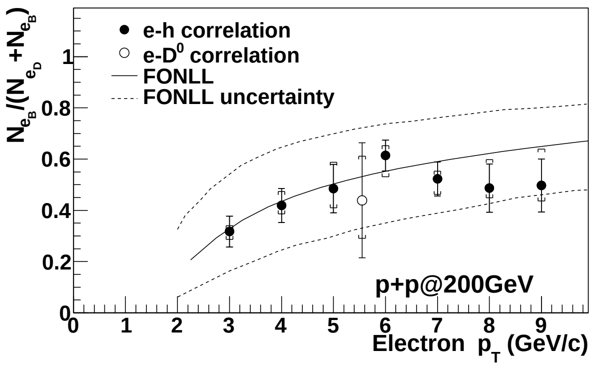

Figure 2: Transverse momentum dependence of the relative contribution from B mesons to the non-photonic electron yields [10]. Error bars are statistical and brackets are systematic uncertainties. The solid curve is the FONLL calculation [4]. Theoretical uncertainties are indicated by the dashed curves.

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 v_2. Thus the v_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 π^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 $M_{e^+e^-}$ [12]. Figure 1 gives the example of the measured $e_{non\gamma} - h$ correlations together with PYTHIA calculations showing the different near-side widths when triggering on electrons from D or B mesons [11]. The width difference enables us to carry out a combined fit of PYTHIA D/B calculations to the measured correlations with the only free parameter to be the relative B contribution, r_B. The fit results are shown in Fig. 2 as a function of $e_{non\gamma}$ p_T. r_B increases with p_T and reaches approximately 0.5 around $p_T = 5$ GeV/c, consistent with the FONLL calculation [4] within theoretical and experimental uncertainties. We also estimated that the inclusion of $e_{non\gamma} - h$ correlation from J/ψ decays will not alter r_B significantly within statistical and systematic errors.

Neglecting contributions from charmed baryons, $e_{non\gamma}$ R_{AA} [13] is given by

$$R_{AA}^{non\gamma} = (1 - r_B)R_{AA}^{e_D} + r_B R_{AA}^{e_B}, \quad (1)$$

where $R_{AA}^{e_D}$ ($R_{AA}^{e_B}$) is the R_{AA} for electrons from D (B) mesons [10]. With the current measurement of r_B and the $R_{AA}^{non\gamma}$ measurement from PHENIX [14], we picture Eq. 1 in Fig. 3 for $p_T > 5$ GeV/c, where the solid line represents the most probable values for $R_{AA}^{e_D}$ and $R_{AA}^{e_B}$, 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+Au 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+Au collisions. Fig. 4 shows $e_{non\gamma} - h$ correlations for RHIC run2008 200 GeV d+Au collisions, with the same

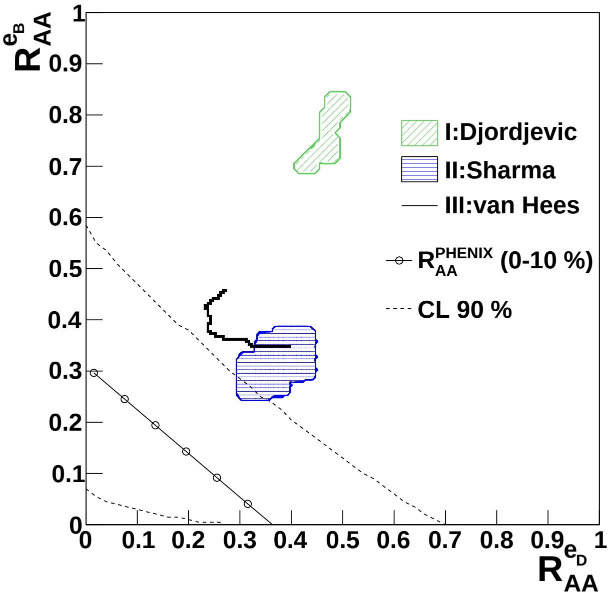

Figure 3: Confidence level contours for nuclear modification factor R_{AA} for electrons from D ($R_{AA}^{e_D}$) and B ($R_{AA}^{e_B}$) meson decays and determined by combining the R_{AA} results and the r_B measurement for $p_T > 5$ GeV/c [10]. Three different models of R_{AA} for D and B are described in the text.

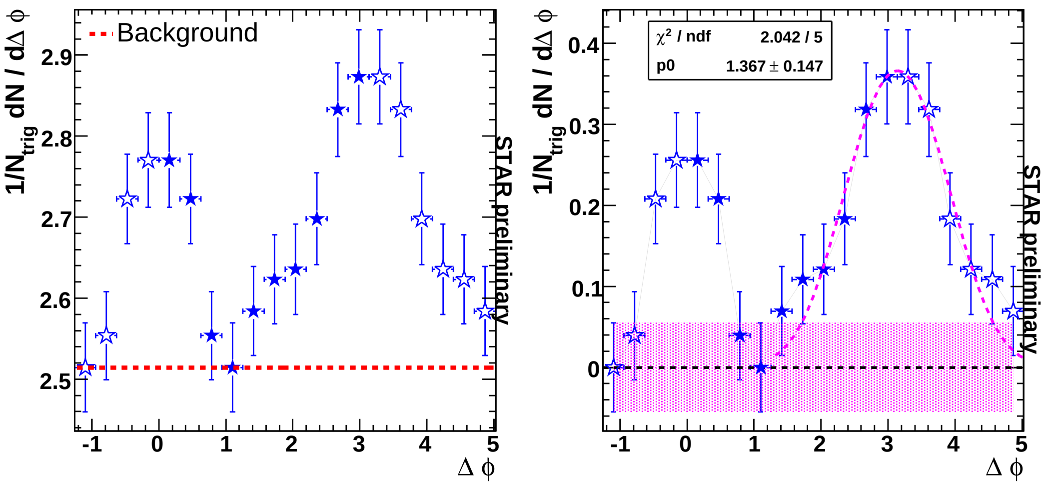

Figure 4: The azimuthal angular correlation between non-photonic electrons ($3 < p_T < 6$ GeV/c) and hadrons ($0.15 < p_T < 0.5$ GeV/c) for 200 GeV d+Au collisions. The open points are reflections. The left (right) panel shows the correlation before (after) background subtraction, with a dashed fitting 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 [19].

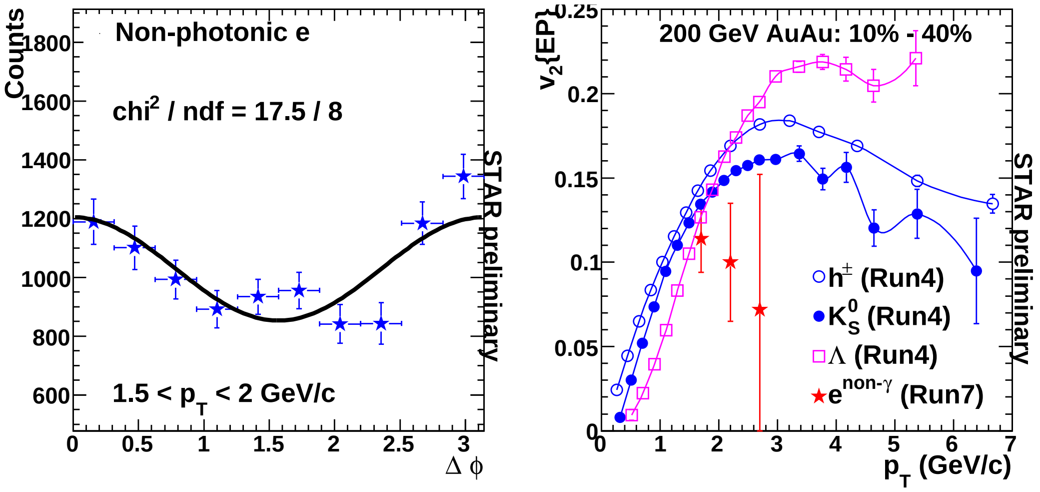

Figure 5: The left panel demonstrates the measurement of non-photonic electron $v_2\{EP\}$, and the right panel shows the v_2 comparison between charged hadrons, K^0_S, Λ [21] and non-photonic electrons.

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 $e_{non\gamma}$ v_2 via its angular azimuthal correlation with the event plane [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 χ^2/ndf to compensate for the fitting quality. The right panel shows the comparison of v_2 between $e_{non\gamma}$ and charged hadrons (K^0_S, Λ) [21]. With the large statistical errors, $e_{non\gamma}$ v_2 is found to be systematically lower than that of hadrons, K^0_S or Λ. 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.

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